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NORTH ATLANTIC TREATY ORGANIZATION

RESEARCH AND TECHNOLOGY ORGANIZATION

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RTO MEETING PROCEEDINGS 38

Modelling and Analysis of Command and Control

(Modélisation et analyse de processus de commandement et de contrôle)

Papers presented at the Symposium of the RTO Studies, Analysis and Simulation (SAS) Panel held at Issy les Moulineaux, France, 12-14 January 1999.

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- SAS Studies, Analysis and Simulation
- SCI Systems Concepts and Integration
- SET Sensors and Electronics Technology
- IST Information Systems Technology
- AVT Applied Vehicle Technology
- HFM Human Factors and Medicine
- NSPG NATO Simulation Policy Group (Modelling and Simulation)

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Modelling and Analysis of Command and Control

(RTO MP-38)

Executive Summary

The NATO RTO Organization, Studies, Analysis and Simulation (SAS) Panel, Technical Team SAS-002 on the Modelling and Analysis of Command, Control, Communications and Intelligence held a symposium on the "Modelling and Analysis of Command and Control", at the Fort d'Issy les Moulineaux near Paris, France on 12-14 January 1999.

A total of 28 technical papers were presented in five sessions. The first session comprised a keynote address and two general technical papers.

The second session dealt with the selection of Measures of Merit for use in C2 assessment, including C2 in the information age, a conceptual model used in policy studies to optimize artillery configuration, a methodology for effectiveness analysis and the use of Petri nets, Bayesian inference networks and battle models to analyse the operational effectiveness of C2 systems on the role of a new attack helicopter. The session also included presentations on model development in the context of effectiveness analysis on the technical, system and operational levels and a summary of the SAS-002 Code of Best Practice chapter on MoM regarding challenges/issues, recommendations and conclusions.

The third session covered C3 modelling and simulation and consisted of five technical presentations covering a variety of subjects, followed by a question and answer period. Topics included a discussion of modular concepts for C2 simulations, a meta-language used for specifying C2 processes, C3I representation in an object oriented design, an automated operational planning demonstrator and the empowering of C2 acquisition with modeling and simulation. Of particular interest was the use of object oriented design techniques in C2 modelling and the extent to which operators must understand these and other techniques.

The fourth session on Human Factors and Organizations gave a good illustration of the multi-dimensionality and complexity of this problem area by ranging from a vision of the future C2 operational architecture through modelling of decision making, description of information, theories and models for information acquisition and processing, to quality criteria for evaluation of user-system interfaces. The subjects dealt with included a future C2 operational architecture concept, a model framework based on cognitive theories of expertise, a "language" termed "Tactical Information Abstraction Framework" for the description of situation perception in maritime studies of situation awareness and data fusion, some theories and models for acquisition processing and representation of information in tactical operations and a set of 27 quality criteria that can be used for comparison of existing and design of future user/system interfaces.

Session five presented examples of C3I assessments, including the recent development of methods which allow the effects of sensor and communications performance to be linked to overall force effectiveness measures, lessons learned from performing analyses of the US Army's Task Force XXI Field Experiment, methods for evaluating competing battle management systems in the laboratory, and Flight Optimisation for Reconnaissance Missions.

The session concluded with a brief account of the contents and conclusion of the Code of Best Practice by the Symposium Chairman, Mr Bennett.

The final session on "Special Topics" focused on the subject "Looking to the Future", with presentations on "The Five Ages of C3 Modelling", the "Representation of C2 in Naval Warfare", "Co-evolving C2 Organizational Processes, Decision Support Technology and Education/Training: The Role of Evaluation in Cognitive Systems Engineering", "Major Challenges Posed by Future C2 Assessments" and "The Way Ahead".

Modélisation et analyse de processus de commandement et de contrôle

(RTO MP-38)

Synthèse

Le groupe technique SAS-002 chargé d'études sur la modélisation et l'analyse du commandement, contrôle, communications et information (C3I), de la commission études, analyses et simulations (SAS) de l'organisation RTO de l'OTAN, a organisé un symposium sur « la modélisation et l'analyse du commandement et contrôle » au Fort d'Issy, près de Paris, France, du 12 au 14 janvier 1999.

En tout, 28 communications techniques ont été présentées lors des cinq sessions du symposium. La première session a consisté en un discours-programme et deux communications d'ordre technique générale.

La deuxième session a traité du choix des « mesures de mérite » à utiliser pour l'évaluation du C2, y compris le C2 à l'ère de l'information, un modèle conceptuel mis en oeuvre dans les études d'optimisation des configurations d'artillerie, une méthodologie pour l'analyse de l'efficacité de l'armement et du C2 et l'utilisation des réseaux Petri, des réseaux d'inférences Bayesiens et des modèles de bataille, afin d'analyser l'efficacité opérationnelle des systèmes C2 vis à vis du nouvel hélicoptère d'attaque. La session a également inclu des présentations sur le développement des modèles dans le contexte de l'analyse de l'efficacité technique, fonctionnelle et opérationnelle, et un résumé du chapitre du Code de meilleure pratique SAS-002 concernant les mesures du mérite (MoM), et en particulier les défis / problèmes, recommandations et conclusions.

La troisième session a porté sur la modélisation et la simulation du C3 et a consisté en 5 présentations techniques, suivies d'une séance de questions et réponses. Les points suivants ont été abordés : les concepts modulaires pour simulations C2, le métalangage pour la spécification des procédés du C2, la représentation du C3I dans une conception orientée objets, le démonstrateur de la planification opérationnelle automatisée et l'amélioration de l'approvisionnement du C2 par la modélisation et la simulation. Toutes ces questions ont suscité un grand intérêt.

La quatrième session, sur les facteurs humains et les organisations, a fourni l'illustration de la complexité de ce problème multidimensionnel, allant d'une vue de l'architecture opérationnelle du futur C2 à la modélisation de la prise de décisions, à la description des théories et modèles de l'information pour l'acquisition et le traitement de l'information aux critères de qualité pour l'évaluation des interfaces utilisateur-système. Un concept de future architecture opérationnelle C2 et un schéma de modèle, basé sur les théories cognitives des connaissances techniques ont été évoqués. Un « langage » appelé « structure d'abstraction d'informations tactiques » a été présenté. Il permet, dans les études maritimes, la fusion des données et la perception de la situation des forces. Des théories et des modèles pour le traitement de l'acquisition ont été montrés, ainsi qu'une représentation de la situation dans les opérations tactiques. Enfin, 27 critères de qualité ont été décrits, permettant de faire la comparaison entre les interfaces utilisateur/système actuelles et futures.

La session cinq a présenté des exemples d'évaluations du C3I, y compris le développement récent de méthodes permettant de faire le lien entre les effets des performances des capteurs et des communications et les mesures de l'efficacité globale des forces, les enseignements à tirer des analyses de l'expérience sur le terrain de la force opérationnelle XXI de l'armée de terre américaine, les méthodes d'évaluation de systèmes de gestion de bataille concurrentiels utilisées en laboratoire et l'optimisation du vol pour des missions de reconnaissance.

La session a été conclue par un résumé du contenu et des conclusions du code de meilleure pratique.

La dernière session, intitulée « aspects particuliers » a eu pour thème « regards sur l'avenir », avec des présentations sur « les cinq âges de la modélisation du C3 », « la représentation du C2 dans la guerre maritime » et « la co-évolution des procédures organisationnelles du C2, des technologies de soutien de la prise de décisions et des techniques d'éducation/formation : Le rôle de l'évaluation dans les systèmes d'ingénierie cognitive », « les grands défis de l'évaluation future du C2 » et « la voie de l'avenir ».

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Discours d'introduction au symposium

par le Général de corps d'armée Marescaux
mardi 12 janvier 9h30 - 10h00

DGA/DSP/SASF
26 Bd Victor
00460 Armées
France

1 - Introduction

C'est avec beaucoup de plaisir que j'ai accepté de participer avec vous à ce symposium de l'OTAN. Aujourd'hui, en effet, la Délégation Générale pour l'Armement (DGA) a pris l'initiative d'accueillir cette manifestation sur le thème de l'analyse et la modélisation des systèmes C3R avec en arrière plan les nouvelles donnes opérationnelles et technologiques de ce vaste domaine.

Il me semble en effet qu'entre les enseignements des conflits récents auxquelles les forces occidentales ont participé et la prospective que l'on peut faire sur la civilisation de l'information, nous sommes parvenus à un tournant quant à l'équipement et à l'organisation des forces dans les opérations futures.

Tous ces sujets ont bien entendu un point focal, l'utilisation des technologies de l'information avec le souci de la cohérence à apporter entre les divers systèmes au sein des systèmes de forces.

Aussi, après avoir rappelé brièvement les éléments caractéristiques du contexte international, j'articulerai ma présentation autour des besoins en systèmes de type C3R, et de la méthodologie choisie en France pour relever ce challenge, avant de conclure par quelques mots sur l'analyse et la modélisation de ces systèmes, objet de ce symposium.

2 – Contexte général pour les interventions d'aujourd'hui

L'effondrement du bloc soviétique il y a maintenant près de dix ans nous a conduits d'un monde structurellement bipolaire, marqué par la présence d'une menace majeure, à un univers multipolaire, caractérisé par la permanence de crises par nature diversifiées et susceptibles de dégénérer comme de proliférer.

La guerre froide avait fait prévaloir une forme particulière de confrontation, programmée au moins dans sa phase initiale, face à un ennemi connu, doté d'équipements connus, sur un terrain connu et avec des alliés connus.

Un conflit sur le "Théâtre Centre Europe" devait revêtir un caractère massif dans lequel, pour reprendre l'expression de Clauzewitz, la totalité de nos forces aurait été engagée en un "seul coup sans durée". Pratiquement la guerre froide se concrétisait par une guerre technologique d'une ampleur sans précédent.

Si la prise en compte de ce type de menace à l'horizon des 30 années à venir ne peut-être écartée, pour la première fois depuis des décennies les alliés n'ont plus d'adversaire désigné, et les territoires nationaux ne sont plus directement menacés.

L'art de la guerre devient désormais l'art de la paix, et passe de plus en plus par une aptitude à la gestion de la complexité. Les conflits sont devenus plus variés dans leur nature (maintien de la paix, prévention des crises...), leur intensité et dans leur localisation géographique. Ce n'est plus à partir d'un seul scénario qu'il faut désormais structurer les outils de défense, c'est à partir de plusieurs scénarios de crises et de conflits que doivent être aujourd'hui basées nos réflexions.

Les nouvelles caractéristiques des opérations sont aussi capitales que les nouvelles donnes technologiques, je pense notamment aux technologies de l'information. L'aptitude opérationnelle de demain dépendra de la capacité à obtenir la synergie entre les unes et les autres.

Il n'est pas aisé de définir un besoin opérationnel, tous les officiers et les ingénieurs le savent depuis longtemps et chaque pays a une approche différente mais je crois cependant que les futures interventions auront toutes un certain nombre de points en commun :

- Les opérations contemporaines sont souvent des opérations de gestion de crise ordonnées et conduites sans préavis, à des distances souvent importantes des bases. Elles nécessitent rapidité de réaction et capacité de projection.

- Les opérations sont interarmées: le commandant opérationnel dose les moyens qu'il prend dans chaque composante d'armée et les assemble. Il faut donc être modulaire, c'est à dire flexible et surtout inter opérable.

- Les opérations sont multinationales. Les opérations ne sont plus le fait d'une seule nation mais généralement d'une coalition à partir d'un mandat international qui peut être délivré par le conseil de sécurité des Nations-Unies ou l'OSCE. Là encore il faut être interopérable et cette interopérabilité doit s'étendre au-delà de nos alliés traditionnels, à tous les membres d'une coalition parfois éphémère.

3 –<u>quelles capacités voulons-nous détenir ?</u>

J'en vois cinq :

- **l'acquisition du renseignement** s'impose quelle que soit l'option stratégique retenue, dissuasion ou prévention. Qu'il soit à caractère stratégique, opératif ou tactique, l'accès autonome au renseignement est un élément essentiel pour l'exercice de la souveraineté;

- **la planification et la conduite des opérations** condition sine qua non d'une participation responsable, pleine et active au commandement d'une force de coalition. L'acquisition et le maintien de cette capacité passent par la prise en compte du caractère "interarmées" des opérations futures et par une recherche permanente de l'interopérabilité des systèmes nationaux avec ceux des alliés (l'ACCS pour les opérations aériennes au sein de l'OTAN est un bon exemple);

- **la domination par la manœuvre** doit se traduire par davantage de mobilité et davantage de précision dans les frappes. La domination par la manœuvre , faut-il le souligner, ne peut exister sans des capacités accrues, de recueil, de traitement et de diffusion des informations nécessaires tant à la compréhension de la situation tactique qu'au traitement des objectifs ;

la capacité de projection enfin impose aux forces de disposer de moyens de commandement et de renseignement projetables et déployables, de moyens de communication avec le commandement de théâtre et de réseaux de communication tactiques;

. **enfin la maîtrise de l'information :** c'est un sujet important qui mérite un développement particulier.

4 – Maîtrise de l'information

Cette maîtrise de l'information permet d'anticiper les décisions de l'adversaire, accélère la manœuvre des troupes amies et optimise l'efficacité des armes. Le renseignement est plus sûr, la frappe plus précise, le contrôle des effets plus rapide : on retrouve les trois principes de l'art de la guerre : " liberté de manœuvre, concentration des efforts, économie des moyens " et les systèmes de traitement automatisé de l'information, d'une part, d'aide au commandement d'autre part, relèvent de cette problématique.

Les enjeux sont clairs : les conflits à venir se dérouleront autour des communications et de l'information : il s'agira de savoir qui fait quoi, quand, où et pourquoi. L'information est désormais l'un des objets de la bataille, c'est le domaine où peuvent être acquis des avantages décisifs aussi bien pour la manoeuvre militaire, opérative et tactique, que pour l'action politique qu'elle appuie.

Dans le domaine médiatique les actions offensives viseront à dissocier les forces et les populations. Dans le domaine opérationnel, il s'agira de modifier la perception par l'adversaire de notre propre situation, de paralyser son système de commandement, tout en conservant un rythme décisionnel rapide.

C'est une bataille non létale où il n'est pas nécessaire de détruire l'adversaire. C'est une bataille où les fronts et les distances n'existent plus et où ceux qui seront capables de contrôler les réseaux et les bases de données auront un avantage énorme.

C'est la raison pour laquelle il s'agit de constituer une architecture de base cohérente, efficace et protégée pour le recueil, la fusion et la diffusion de cette information et de prévoir, en matière offensive, les outils de lutte contre les moyens de commandement adverses.

Si nous revenons à l'objet de ce symposium, je crois pouvoir dire que le champ de l'information en terme d'analyse et donc de modélisation est à approfondir et qu'une réflexion globale est à mener sur les hypothèses et les limites de sa représentation.

5 – Synergie entre le Commandement et les SIC

Je voudrais maintenant parler des systèmes d'information et de communication, les SICs qui ont un effet multiplicateur sur le commandement et le contrôle des opérations.

Le couplage des possibilités d'un SIC avec le fonctionnement des postes de commandement (PC) est un facteur de cohérence important. Ainsi, un PC doit en priorité se comporter comme un centre d'acquisition, de tri, d'analyse, de synthèse et de diffusion de l'information; il doit être perforant, réactif et réaliste. Vous savez qu'on distingue les PC d'opérations et les PC tactiques, mais les uns et les autres comportent une cellule de conduite travaillant en temps quasi réel.

La gestion de la complexité impose des méthodes de travail rigoureuses et aussi l'organisation de nombreuses réunions qui nécessitent l'utilisation de la vidéoconférence plusieurs fois par jour.

L'efficacité des PC dépend de la transparence interne que créent les systèmes d'information et des méthodes de travail d'état-major où la logique fonctionnelle doit trouver sa juste place par rapport à la logique hiérarchique.

Si l'on s'intéresse au niveau opératif, les PC peuvent également être caractérisés par deux mots supplémentaires : adaptabilité et évolutivité.

- Adaptabilité pour tenir compte de l'éventail complet des opérations (de l'action humanitaire de simple accompagnement à l'imposition de la paix en passant par tous les types de restauration de la paix) et pour envisager l'intégration de représentants d'organisations très diverses.

- Evolutivité pour introduire certaines fonctionnalités nouvelles qui demandent dès maintenant un fort investissement en études. C'est le cas par exemple pour la simulation qui est complémentaire de la planification, qui sera demain l'outil majeur de l'aide à la décision et qui pourra devenir l'outil d'une pression psychologique sur l'adversaire.

L'aptitude au commandement opératif impose des liaisons suffisantes et de qualité avec l'ensemble des correspondants. En terme de réseaux, il s'agit de réseaux locaux, opératifs et stratégiques. Peu importe que l'information passe par un réseau de telle armée ou par un satellite civil, peu importe le copyright du logiciel utilisé, chaque poste de travail doit pouvoir effectuer l'ensemble des tâches pour lesquelles il a été défini.

Le volume des informations à transmettre se chiffre désormais en mégabits par seconde tant vers le commandement de l'opération que vers les commandants de composantes tandis que les distances s'accroissent.

Je voudrais insister sur la flexibilité des futurs SIC pour la meilleure adaptation à des PC qui doivent pouvoir se reconfigurer en fonction des circonstances.

La convivialité des stations de travail est aussi à considérer comme primordiale. Des traitements automatiques et des applications spécifiques facilitent le travail des rédacteurs tandis que la simulation des phases de l'opération valide les travaux de planification.

Chacun peut joindre ses correspondants pour un simple échange d'information ou pour écrire en commun un ordre d'opérations. On discute par messagerie de façon totalement informelle avant de se transmettre des documents officiels. On "pousse" et on "tire" l'information, on accède aux banques de données pour coordonner une planification ou conduire une simulation.

Cependant on sait bien que l'information reste fragile et donc l'intégrité des SIC reste d'une grande importance même si le besoin d'une transparence interne de l'information est exprimé. La protection des informations, la fiabilité des systèmes et la garantie de service indépendamment des supports utilisés restent des éléments cruciaux.

Pour terminer sur ce point, je voudrais insister sur le partage de l'information qui est synonyme de réussite et que les différents analystes des SICs doivent bien prendre en compte.

6 –La préparation de l'avenir en France avec les systèmes de forces et le plan prospectif à trente ans

L'état-major des armées et la DGA, en concertation avec les états-majors d'armées (Terre, Marine, Air), ont décidé de raisonner désormais, pour la préparation de l'avenir, par systèmes de forces.

C'est un ensemble de moyens correspondant à une grande mission ou à une grande fonction exercée par les forces armées. On en a retenu huit :

- Cinq d'entre eux, privilégient la cohérence des moyens par fonction opérationnelle (dissuasion, commandement-conduite-communication-renseignement, mobilité stratégique et tactique, frappe dans la profondeur, préparation et maintien de la capacité opérationnelle).

- Trois autres privilégient la cohérence par milieu (maîtrise des milieux aéroterrestre, aéromaritime et aérospatial).

L'étude d'un système de forces représente bien ce carrefour de la technique, de sa technologie et de son utilisation potentielle pour une mission ou une fonction militaire. Les paramètres techniques sont les caractéristiques et les performances propres de chacun des éléments constituants comme les transmissions et les traitements de l'informations. Les paramètres opérationnels sont des modalités d'emploi (positions, mouvements, règles d'affectation des cibles, politique de tir...). Et les uns et les autres se trouveront réunis dans une modélisation commune qui permet de produire des évaluations, des comparaisons et des optimisations.

Le document de base pour notre travail est le plan prospectif à trente ans (PP30). Il réunit les éléments nécessaires pour préparer les nouveaux programmes d'armement et orienter les actions de recherche en conséquence. Il envisage pour cela les évolutions qui, sur le long terme, pourraient bouleverser le champ des menaces et le spectre des technologies utilisables

Le PP30 couvre la période des trente années à venir. Il permet de disposer d'une vision prospective sur un horizon qui correspond au cycle de vie des "plates-formes" (blindés, bâtiments de la marine, avions, hélicoptères). Et il est bâti selon le raisonnement par systèmes de forces qui favorise, comme on l'a vu, la cohérence au niveau global.

Le PP30 est l'outil principal pour orienter les études amont (EA) et les études technico--opérationnelles (ETO) à partir des besoins militaires futurs. Le PP30 est à son tour alimenté en retour par les résultats des EA et des ETO de l'année écoulée. En définitive, ce plan prospectif oriente les travaux dont les résultats doivent permettre de faire les bons choix aux bons moments pour lancer les programmes futurs.

7– Les Etudes Technico-Opérationnelles (ETO) et la simulation

Je voudrais ajouter quelques mots sur les ETO qui existent sous des vocables divers chez les alliés et qui constituent un élément-clé de la préparation du futur.

Elles permettent de préciser les besoins et d'optimiser les choix techniques, d'obtenir un meilleur rapport coût/efficacité des systèmes d'armes et d'assurer leur adéquation maximale aux missions opérationnelles auxquelles ils sont destinés.

Elles s'intègrent bien dans la démarche par systèmes de forces qui prend sa source dans le PP30 et je peux dire qu'aujourd'hui, le couplage du plan prospectif avec ces études est déjà prometteur et renforce la caractère global et cohérent de notre démarche.

Ces ETO doivent nécessairement s'appuyer sur des techniques d'analyse. La simulation en est une de premier plan et elle s'est d'ailleurs répandue parmi toutes nos nations après que les Etats Unis aient montré la voie depuis plus d'une vingtaine d'années.

Il est à remarquer que ces techniques de simulation sont aujourd'hui utilisées dans toutes les sciences. Elles utilisent des modèles qui présentent une version abstraite et réduite de la réalité. Cette démarche se situe entre les deux autres voies que sont la théorie pure et l'expérimentation.

La simulation constitue pour la Défense un enjeu stratégique, grâce à sa capacité de représenter la réalité et d'éviter ainsi les spéculations de la théorie pure. Elle remplace avantageusement les opérations réelles dans des domaines difficiles à explorer par l'expérimentation directe.

Comme vous le savez, la simulation peut ainsi apporter une aide dans quatre grands champs d'application:

- La préparation des forces en facilitant l'entraînement des unités opérationnelles, le développement des stratégies et des tactiques, l'évaluation des plans opérationnels, l'aide à la planification, l'aide à la décision opérationnelle par l'évaluation des résultats.

- L'étude de nouvelles organisations des forces par une modélisation réaliste. Elle remplace avantageusement les opérations réelles dans des domaines difficiles à explorer par l'expérimentation directe. Elle revêt à cet égard un aspect culturel important, dans la mesure où les opérateurs formés grâce à la simulation adhèrent plus aisément aux organisations qu'ils ont utilisées dans ces simulations.

- La conception et la réalisation des nouveaux systèmes en optimisant les délais, l'emploi des ressources et en réduisant les risques tout en augmentant la qualité des processus de faisabilité, de définition, de développement d'industrialisation et de production.

- Le soutien logistique enfin, en fournissant un modèle réaliste du cycle de vie des forces intervenantes dans une opération.

Face aux nouvelles stratégies internationales fondées sur des alliances multiples, la simulation trouve naturellement sa place. Elle devient un des moyens essentiels d'étude des systèmes et des organisations, de l'entraînement et de la logistique.

8- Conclusion

J'arrive à la conclusion de mon exposé car il va bientôt être temps de laisser la place aux divers experts de ce symposium.

Je voudrais d'abord dire que la civilisation de l'information est devant nous. Toutes les techniques et technologies qui l'accompagneront sont amenées à se développer mais ceci ne doit pas altérer notre lucidité. En effet, il ne faut pas oublier que le progrès technique, certes fascinant, n'est pas un but en soi. Il ne suffit pas de cultiver les "technologies de pointe" pour être assuré de détenir demain les meilleurs armements. Les technologies, qu'elles soient ou non "de pointe", doivent être correctement évaluées et optimisées quant à leurs caractéristiques techniques et leurs modalités d'emploi avant d'être incorporées dans les systèmes.

C'est là tout l'intérêt de l'analyse technico-opérationnelle qui a pour objectif premier la compréhension et l'évaluation des phénomènes et des processus avec comme finalité la cohérence

globale. J'ai noté, à ce sujet, le bon travail du RSG sur " la modélisation et l'analyse des systèmes C3R " qui s'est traduit par un document méthodologique (le Code of Best Practice). Je constate avec intérêt le souci d'apporter des réflexions fondamentales en amont des processus d'acquisition. A cet égard, il est utile d'approfondir quelques questions de fond, que je soumets à votre réflexion :

- Quel doit être le poids réel des systèmes du C3R d'après les différents scénarios d'emploi ?

- Quelle est l'optimisation souhaitée et possible en terme de structure et d'organisation des forces dotées des nouveaux systèmes d'informations ?

- Comment mesurer l'intérêt de tel ou tel système de traitement de l'information et avec quels critères technico-opérationnels ?

Replaçons ce problème dans son contexte : les opérationnels ont défini les outils dont ils ne sauraient se passer pour conduire les opérations. Il s'agit de disposer non seulement de réservoirs de forces mais aussi de réservoirs d'états-majors parfaitement entraînés et équipés, qui ont pris toute la mesure de la révolution culturelle dans le domaine des systèmes d'information et de télécommunication, et qui sont également conscients de ce que les contraintes budgétaires les obligent à obtenir le meilleur rapport coût - efficacité pour leurs systèmes.

Bref, le monde technico-opérationnel n'échappera pas à une certaine " globalisation " de son domaine et les analystes techniques et opérationnels prendront de plus en plus d'importance dans la préparation du futur. Je crois donc pouvoir dire que vous avez de belles années devant vous.

Je vous remercie de votre attention et je vous souhaite un très bon symposium.

THE ANALYSIS OF COMMAND AND CONTROL

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Introduction

Across NATO, there is a growing realisation that the proper representation of Command and Control (C2) within combat models is very important. Some of the reasons for this are:

a. To show the cost-effectiveness of investment in C2 systems.

b. To support Defence programmes such as 'Digitization of the Battlespace'.

c. The need to represent C2 in order to properly represent overall force behaviour and effectiveness. This includes the need to incorporate emerging understanding of the human impact on operational effectiveness.

There is thus an urgent need to develop methods of properly representing these effects. In consequence, research has been instigated in the UK to investigate ways in which the effects of C2 can be incorporated successfully into constructive simulation models of combat - i.e. simulation models which can run in closed form on a computer, and represent the effects of C2, without the need for human intervention during the simulation run.

A major pressure acting on defence operational research studies is the need to address a wider span of likely futures (*scenarios*) in studies, reflecting increased uncertainty in the post-Cold War world. Another reflection of this uncertainty is the need to consider a wide range of sensitivity analysis, and to do this quickly enough to influence the political process. These point to the need for constructive simulation models, incorporating the effects of C2, which run at rates very much faster than real time, and which are easily transportable across different situations and scenarios.

There have been several attempts in the last thirty years to develop simulation models of war which have a proper representation of the C2 process. Proper here means sufficiently good that the models can be used with confidence for studies to advise ministers and other high level public sector decision-makers on major defence budget expenditure (running to billions of pounds) and preferred future force structures for the defence of the country. In such circumstances Operational Analysis (as Operational Research is called in the Ministry of Defence) is subject to another pressure which is to represent processes in sufficient detail to give confidence that the results can be trusted. There is thus a need to strike a balance between such detail and the need for rapid analysis of alternatives. This is the key research challenge.

Previous attempts at representing the C2 process in the NATO defence communities have adopted rule based approaches based on expert systems. These have led to models which are slow, difficult to understand, and very difficult to transfer from one scenario to another. They are thus not suited to the new post-Cold War defence environment. A new approach is laid out here, which shows sufficient promise that the ideas concerned are being incorporated into the next generation of simulation models under development at the Centre for Defence Analysis. These models are designed to span the range of likely future defence environments, ranging across Land, Sea and Air, and including lower level operations such as Peacekeeping.

In the next section, we discuss the agent based architecture which underpins the approach.

Command Agents and Agent Based Architecture

The Command and Control process of a military operation is carried out by a number of Headquarters (HQs) or 'Command Agents' interacting in some kind of network (normally a hierarchy of some sort). One part of the research is looking at how this network of HQs can be represented in as generic a way as possible. That is, the *process architecture* of the operations of the HQ should be the same, wherever, the HQ is located in the network. Clearly, the way in which these functions are carried out by the HQs will differ, dependent on their role. The other part of the research is thus looking at how to capture the way in which the HQs go about their business (the *functionality* of the HQ).

A recent NATO workshop on this subject (1) brought together current best practice across NATO, and amongst other things, confirmed that the most difficult parts of the representation of C2 are the functions of Data Fusion, Recognised Picture Compilation, and Decision Making leading to the formation of a plan . These represent the core processes of an HQ in evolving a set of perceptions of the outside world from sensor and situation reports, (*Data Fusion*), developing a 'picture' or mental model of what is going on, (the *Recognised Picture*) and then forming a plan of what to do next, given the overall aims of the campaign, and the current mission (*The Planning Process*).

Rule based Approaches

As touched on earlier, The history of attempts at modelling the C2 process in simulation models of combat is not a happy one. Much expenditure and large modelling efforts within the NATO defence community have not produced a commensurate return. Part of the reason for this is that all serious attempts within NATO up to now (that is, attempts which aim to significantly influence the budgetary and political process) have used a *rule-based approach*. This means that the decision process of the commander is represented by a very large set of interacting decision rules. This produces very complex models which are difficult to understand, and are slow running. Because many of these rules are scenario dependent, great effort is required to capture a range of such scenarios. In the post-Cold War world, a new approach is needed. For these reasons, the research reported here deliberately avoids the use of such decision rules where at all possible. This is recognised as a high risk approach, but with potentially a high payoff.

The Testbeds

The basic approach of the research is firstly to establish the structure of a 'Generic Headquarters (HQ)', or Command Agent, and then to try out that structure in a number of prototype 'testbeds'. These testbeds are constructive simulations of combat, at different levels of force representation, and representing different forms of warfare. Such an approach is intended to lead to a generic representation of the C2 process, which is applicable across a wide range of simulation models.

The approach has been developed in an evolutionary manner, using the software testbed environments to develop particular representations of functionality, and to explore the resultant model behaviour. The three simulation model testbeds currently in use are CLARION+ ,a development version of the CDA CLARION theatre level model of land/air war; MOSES, a prototype model of aspects of peacekeeping operations; and HiLOCA, a Corps level representation of land combat based on cellular automata.

Agent oriented approach

An object oriented approach within these testbed models allows different objects to be brought together to represent the complete command process, rather like building bricks. Such a philosophy also allows the research to proceed based on *holistic* and *evolutionary* principles. In other words; always hold a complete model of the process , including the parts whose representation is still unclear. As understanding develops, improve those parts (or objects) which were rudimentary to start with.

Object Architecture and Functionality - Overview.

The structure of the Generic Command Agent is based on the well known OODA (Observation, Orientation, Decision, Action) cybernetic loop. The Generic Command Agent thus consists of five object class categories as follows:

Communications Class - represents all transmission and receipt of information.

Observation and Orientation Class - represents the production and maintenance of the Recognised Picture.

Decision Class - represents the planning process.

Action Class - represents the issuing of orders and reports.

Information Store Class - represents the storage of relevant information by the HQ.

The object architecture described above is the same, irrespective of the position of the HQ in the command network or hierarchy. However, the way in which these processes are carried out will differ, to reflect the fact that HQs at different levels in the organisation carry out their tasks in different ways. This is reflected in the *functionality* of the classes.

In general, then, a number of these generic HQs interacting together will represent the total C2 process.

Command Agent Architecture

Figure 1 shows the key processes of the command agent. These key processes are described in more detail in the next few paragraphs.

The Communications Class
This represents all the processes of communication of information within the HQ and between different HQs. Different types of communication link can be represented, including fixed links and free space propagation, allowing the representation of a wide range of bearer systems.

Observation and Orientation Class
Information is fused and input into the Recognised Picture which corresponds to the HQ's perceived view of the world. This process can alert the planning process if necessary, which can generate Commander's Critical Information Requirements for collection by sensors. The Recognised Picture (RP) is represented by a series of zones, each of which corresponds to an area of military interest.

The Decision Class
This creates the plan on the basis of the commander's recognised picture. The plan is defined in terms of a Gannt chart which lays out the required missions of subordinate units. These missions are drawn from a small list of allowed missions, based on military doctrine.

The Action Class
This can create messages and orders of various types. It sends orders to the units on the basis of the plan, and creates messages such as situation reports and requests for information, All of these are sent through the appropriate communications bearers.

Information Store Class
This stores the Recognised Picture, and any other relevant information.

HQ/Command Agent Functionality

Underpinning Ideas from Complexity theory and Cybernetics
Combat is , by its nature, a complex activity. Ashby's Law of requisite variety, which is discussed for example in (2) and which emerged from the theoretical consideration of general systems as part of Cybernetics, indicates that to properly control such a system, the *variety* of the controller (the number of accessible states which it can occupy) must match the variety of the combat system itself. The control system itself, in other words, has to be complex. Some previous attempts at representing C2 in combat models have taken the view that this must inevitably lead to extremely complex models. However, recent developments in Complexity Theory - see for example (3), indicate another way forward. The essential idea is that a number of interacting units, each with relatively transparent behaviour, can generate extremely complex emergent behaviour, corresponding to an extremely large number of

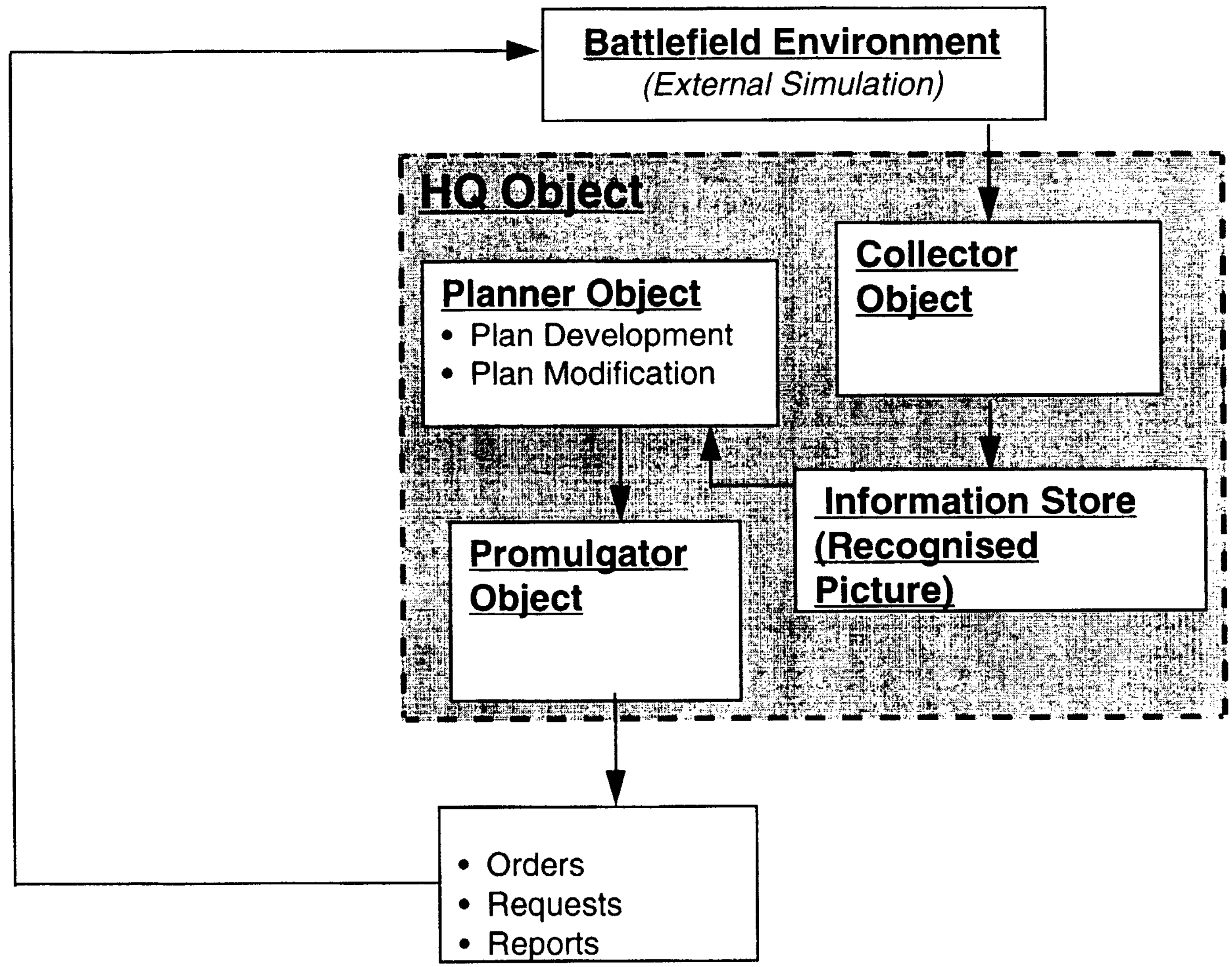

Figure 1: Command Agent Key Processes

accessible states, or a *high variety configuration*, in Cybernetic terms. It follows that, if we choose these interactions carefully, the resultant representation of C2 will be sufficient to control, in an acceptable way, the underlying combat model. Reference 4 supports this conceptual view of the problem. As part of this careful choice, we need to ensure that the potentially chaotic behaviour generated from the 'bottom up', is damped by a top down C2 structure which remains focused on the overall, high level, campaign objectives. This interaction between bottom up and top down allows us to capture all likely command structures as discussed next.

Alternative command structures

In (5), a number of differing command arrangements are described which span the major approaches to the C2 of armed forces. This categorisation is based on broad ranging historical research carried out by the US Defence Information Systems Agency into command arrangements including those in the US (in World War 2 (WW2), Korea, Vietnam and various crises), the UK (in WW2 and the modern period), the USSR (in WW2 and the modern period), Israel (in 1956,1967,1973), China (in the modern period), NATO and others. From the discussion in (5), it is clear that varying command structures can be captured by a combination of top down and bottom up approaches, as shown in Figure 2. Recent UK doctrine has moved more to the bottom end of this spectrum, as 'mission command'. From a historical point of view, this interaction between lower and higher levels is well discussed by van Creveld (6) in his consideration of command in mobile, or manoeuvre warfare, particularly as applied by Napoleon.

This structural issue was also discussed in (7). One of the central issues identified behind the provision of C2 capability was the balancing of centralised and decentralised control - of local autonomy with top down authority. It was observed that the C2 organisation requirement depends on the ratio between C2 speed and battle speed: if the battle speed increases beyond a certain point, then C2 reverts to local organisation (that is, the system becomes self-organising). A similar point is made in current UK army doctrine concerning command (8): 'The more fluid the circumstances, the lower the decision level should be set'.

In summary, any representation of the C2 process must be able to represent the interaction between these top down and bottom up effects. In the next section, this approach is used as a basis for representing the C2 process as a combination of both top down ('Deliberate Planning') and bottom up ('Rapid Planning') processes.

Rapid Planning

UK army doctrine (8) relates command function to the level of command, denoted 'High Command' (at the military strategic and operational levels) and 'Battle Command' at the tactical level. From now on we shall refer to these two command functions as Deliberate Planning (relevant to the military strategic and operational level) and Rapid Planning (relevant to the tactical level). The amount of time available for planning is also a key determinant in which of these approaches is most relevant. This is normally tied quite tightly

- Order Specific
  - Soviet Union
  - Chinese army
- Objective specific
  - UK/US
- Mission specific
  - WW2 Germany
  - Israeli army

Top Down

Bottom up

Figure 2: Alternative Command Structures

to the command hierarchy. As discussed above, the combination of these two approaches to planning captures the variety of different overall command structures likely to be experienced in practice.

As the operational dynamic becomes more fluid (i.e. the ratio of battle speed to C2 speed increases) the system tends to move towards self-organised local command, as we have discussed. Lack of time at the tactical level due to the increase in this ratio of battle to C2 speed will lead to an increase in more 'intuitive' approaches to decision-making (8). The use of such approaches (termed 'naturalistic decision-making') has been observed in an analysis of decision-making during high level UK military wargames (9). These approaches conform to Klein's Recognition Primed Decision -Making (RPDM) model of the decision-making process (10), applicable to expert decision-makers under stress. Discussion with Klein (7) has confirmed the applicability of this model to our problem.

The essence of the RPDM approach is characterised by the following description (9). 'In essence, the process begins with the decision-maker considering the situation or problem and trying to recognise familiar aspects of it. If this can be done, he is very likely to retrieve a satisfactory response from his repertoire and will then check this solution by mentally simulating its progress........'. It can thus be considered as a form of pattern matching, where the current perceived situation is compared with a set of mentally stored references (which have been accumulated by experience and training). The best match then gives rise to a potentially feasible course of action. Reference 9 then goes on to say: 'If the situation is not completely familiar, the decision-maker is likely to engage in seeking more information, or in some causal reasoning to account for the perceived aspects of the problem'. Figure 3 below shows the main steps in the Klein Recognition Primed Decision-Making process, and is drawn from (9).

Pattern Matching

In order to capture the essence of the RPDM approach, the Rapid Planning process thus uses a form of pattern matching, where the patterns are directly linked to possible courses of action. This is achieved by exploiting the mathematical properties of the Dynamic Linear Model (DLM) (see reference 11).

In analysing the commander's approach to Rapid Planning, the US/UK review (7) confirmed the need to consider first the idea of an 'OK' and 'not-OK' situation. Klein in particular made the point that commanders have a general sense of how things are going, which is captured by the idea of OK/not-OK mission states. They take the information they have and weave it into a plausible story (the OK state). At this level, what is required is a method of assessing when the commander is approaching the boundaries of the OK state (7). While the perception of the pattern of events is such that the commander is in the OK state, he remains in his current mission. When the perception is that the pattern of events has significantly changed, he crosses the boundary of the OK state and has to decide whether to remain with his current

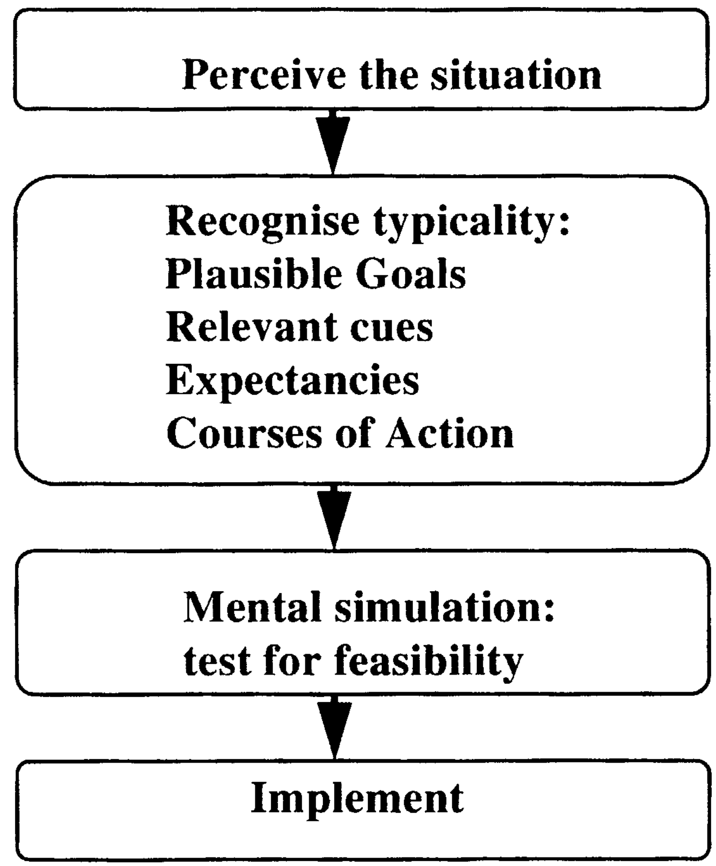

Figure 3: Main Steps in the RPD Process

mission, or change to a new mission. Corresponding to the spirit of mission command, (the lowest of the three levels of C2 structure discussed earlier) it is assumed that there is a small set of alternative missions defined (such as advance, attack, defend, delay, withdraw, or alternatives in other domains such as maritime warfare). These missions are applicable to any level of command, so that the process is recursive. Thus the Rapid Planning problem is the same at every command level; namely whether to move from one of these missions to another, at any given point in time.

The 'perceived pattern of events' is the Recognised Picture and will in general be defined by a number of attributes. A key one is perceived combat power ratio (PCPR), i.e. the perceived force ratio in the commander's local area of interest. There will be other factors which are also important in Warfighting (such as logistics status), and there may be a totally different set of factors applicable to Peacekeeping Operations. The approach to Rapid Planning is thus as follows:

- Quantify the current values of the factors which constitute the Recognised Picture (RP).
- Determine whether the RP has changed significantly. If not, then the situation is OK, and no mission change is required.
- If the situation is changing significantly, (i.e. we are moving into the not-OK situation), compare the pattern corresponding to the recognised picture with a set of fixed patterns which represent the commander's stored understanding.
- Find the best match.
- Test the course of action associated with this pattern for feasibility.

If feasible, implement mission change.

A summary of each step in the process (without the mathematical details) is given below.

Quantifying the Recognised Picture

The Dynamic Linear Model (DLM) uses Bayesian methods and Kalman Filtering to transform the time varying factors which make up the Recognised Picture, into probabilities that each of the fixed patterns (representing the commander's stored understanding) is the correct one. Each of the fixed patterns consists of a multivariate normal distribution, defined by a vector of mean values, (one for each factor in the recognised picture) and a covariance matrix which represents the variance of these factors and their correlation. The DLM takes the time varying data for each of the factors, and computes a multivariate normal distribution, defined by the vector of assessed current mean values (one for each factor), and the assessed covariance matrix for the factors.

A simple example: A simple example will help to clarify what is going on here. Let us assume that the single factor which makes up the recognised picture is force ratio (the PCPR) in the commander's local area of interest. We assume that the level of Blue forces is known, so that the DLM has to estimate the current mean value of enemy strength, and its variance. A prior normal distribution (m_{t-1}, C_{t-1}) with mean m_{t-1} and variance C_{t-1} represents the DLM

assessment of enemy strength at time t-1. Sensor data giving the current perceived strength level is combined with this to give an assessment of enemy strength at time t corresponding to the distribution (m_t, C_t). If O_t is Blue force strength at time t, the distribution of PCPR is $(\frac{m_t}{O_t}, \frac{C_t}{O_t^2})$. (Note: it may also be necessary to track O_t in the same way if there is uncertainty in assessed Blue strength).

OK or not-OK

The next step is to determine whether the situation is still OK (no action required by the commander), or not-OK (a change of mission may be required). This is captured by having a number of potential DLM models of the process (these are described as Class II mixture models in (11)). These models correspond to hypotheses in the commander's mind about what is going on. The first of these models assumes that there has been no significant variation in the factors constituting the recognised picture. This corresponds to the OK state. The other models test whether the vector of data corresponding to the value of the factors of the RP at time t corresponds to a significant deviation. A number of models are required for this to discriminate between such things as transient behaviour, significant changes in level of the vector values, and significant changes in the slope (i.e. the rate of change) of the variables. A minimal set of such models consists of three. The first is the stable model (assuming no significant change). The second tests for transient change, while the third combines level and slope changes into a test of significant, non-transient change. At each timestep t, a probability can be associated with each of these models, as described in (11), based on their relative likelihood. The boundary of the OK state is crossed at points where the probability of the stable model drops and the probability of the change model increases rapidly. Thus tracking these probabilities can be used to estimate when the commander is 'approaching the boundaries of his OK state', and needs to consider what to do about this.

Simple example: Continuing with our simple example, three DLM models could be employed. The first of these corresponds to the commander's hypothesis that the enemy force level, based on sensor observations at time t is essentially the same as it was at time t-1. The second model corresponds to the hypothesis that the change is just a transient 'blip', and the third model corresponds to the hypothesis that there has been a significant underlying change. Each of these has a computed probability, which varies as a function of time, and is driven by the sensor input data. Tracking these three probabilities can be used in the simulation model as an indicator that the commander may have to (or may desire to) change his mission.

Finding the best match

At this stage of the process, we need to compare the observed pattern of the factors comprising the RP, at time t, with a set of fixed patterns corresponding to the commander's store of experience in his long term memory. If there are n such factors, the observed pattern consists of an n-dimensional multivariate normal distribution. The mean of this distribution corresponds to the best estimate at time t, of the mean values of the factors constituting the RP. The covariance matrix of the distribution consists of the variances of these factors, and the correlations which exist between them. Each of the fixed patterns has the same structure.

The amount of overlap (in n dimensions) between the observed pattern and each of the fixed patterns is used to estimate the likelihood of each of the fixed patterns at time t. This is multiplied by the prior probability of the fixed pattern (from time t-1) to give the probability at time t of that pattern being the most appropriate. The pattern with the highest probability is then selected. A commander with an open mind will tend to keep his prior probabilities at a reasonably high default level (never falling below 0.1 for example), while an extremely stressed commander, or one with a closed mind, will tend to allow these prior probabilities to drop to low values, focusing more and more on just one or two options. These two approaches can both be captured in the algorithm.

If there is no good match or if the situation is very uncertain (so that all patterns are equally likely) the commander will wait and seek further information rather than change his mission. If this is conceptualised as a cusp catastrophe surface (12) this is equivalent to delay due to an increased splitting factor, where the value of the splitting factor is proportional to the amount of uncertainty in the local situation. The variance associated with estimates of enemy force levels in different parts of the commander's Recognised Picture can be used to direct his sensors to best effect.

Simple example: For our example, with just one factor in the RP (the PCPR), each of the fixed patterns is a normal distribution characterised by a particular mean and variance. The DLM gives an assessment of the observed distribution of PCPR as $(\frac{m_t}{O_t}, \frac{C_t}{O_t^2})$ as discussed above. The overlap between the observed and fixed patterns corresponds to the likelihood of that particular fixed pattern being the most appropriate. This is multiplied by the prior probability of that pattern for time t-1 to estimate the overall probability of that pattern being the best match at time t. These probabilities are then used to select the best pattern.

Continuing with our example, each of these fixed patterns is tied to a particular desired course of action. This is done by relating the mean of the pattern to a particular mission as follows:

Mean value of PCPR (enemy/own forces) for pattern	Mission
0	Advance
1	Attack
3	Defend
7	Delay
10	Withdraw

Since there is a one-to-one relationship between each of the fixed patterns, and a Course of Action (a mission), the fixed patterns correspond to fuzzy set membership functions (13). The process we have described can thus be considered to be a form of (adaptive) fuzzy set pattern matching. In general, these fuzzy sets are multi-dimensional, corresponding to the number of dimensions of the fixed patterns. Continuing with our simple example, a PCPR observed distribution with a mean of 5 would overlap with the patterns with means of 3 and 7. The commander can thus regard himself as having a fuzzy membership of the mission 'Defend',

and the mission 'Delay'. The relative amount of this overlap (i.e. the relative likelihood) will determine which of these he goes for.

Testing for feasibility

The final step in deciding whether or not to change the mission, is deciding whether such a change is both feasible and desirable, taking account of all the relevant factors. One key factor is clearly the influence of the top down command process. This can be captured by defining templates which represent the core mission 'states' at the lower level of command corresponding to the mission 'state' at a higher level of command. The effect of the bottom up creation of system variety is then captured by defining the number of command cycles for which the subordinate commander is allowed to deviate from this core mission 'state'. This allows the subordinate commander to undertake a constrained random walk among the mission states, while being continually influenced by the top down command process. Because the transition from one mission to another depends on the perception at that time, this process is 'Markov like' (a phenomenon observed in the wargames described at (14)).

If feasible, implement

The final step in the process is to take the mission, as decided using the approach described above, and to apply it to the unit associated with the local commander. At this point, we move from the 'C2 world' back into the 'battlespace' world, and the normal combat processes take over.

Deliberate Planning

It is currently standard practice to employ a lot of military expertise and map based analysis to determine likely broad courses of action at the campaign level for both sides. No model of combat can replace this human expertise. However it is necessary to include in the model the fact that at this level, perception of the other side's intent (this is, his broad course or courses of action) is imperfect, and is a function of intelligence and sensor information. At this level, each of these alternative courses of action can be described by a route through a number of zones. Each of these zones represents a significant piece of terrain (such as an area of ground of a particular type, or an area of sea of constant sonar conditions). For each of the two sides, each of the enemy intents (i.e. enemy Courses of Action) is assigned a prior probability, and these are updated using a bayesian approach as information from sensors looking at the various zones is updated. Denoting the two sides as Blue and Red, Blue's problem is to define a general layout of his forces, taking account of the probabilities of the different perceived Red intents. Red also has the same problem in relation to Blue, and the structure of this process is akin to a hypergame, where each side in a two-person game has a separate payoff matrix based on perceptions. Given an allocation of forces by both sides, the first problem is how to assess the effectiveness of such an allocation. This is done through the use of historical analysis, which is discussed next.

The Historical Analysis approach

Historical Analysis has been used by CDA (15) to represent an attack on a region by an attacker operating on one or more military axes, as a high level wargame. The attacker allocates his available ground forces between these axes, possibly holding some forces in

reserve. The defender may or may not be initially in place on each axis; he will also have forces in reserve which he can move up to meet the attack. Both sides have a number of air sorties available each day, which they can allocate between the axes. The game is designed to be played with only one side attacking at a time, and is broadly based; it is not intended to give a detailed representation of the impact of counterattacks, or a detailed representation of manoeuvre warfare. Each day, the attacker advances on each axis by an amount which depends on

a). The force density ratio on that axis (i.e. the force ratio normalised per unit of frontage).
b). The nationality of the defender forces.
c). The degree to which the attacker has air superiority.
d). The nature of the terrain.

On each day, Historical Analysis non-linear regression equations allow the calculation not only of advance rate, but also of casualties, the probability of immediate attacker breakthrough, the probability of ultimate attacker success on that axis (based on force density ratio and degree of air superiority), and the probability of ultimate attacker success.

This wargame has been adapted for use by the Deliberate planning level of the C2 process as follows:

a). A Course of Action (CoA) (i.e. a Campaign Plan) available to the Blue or Red high level commander, corresponds to a set of military axes of the wargame.

b). For each choice of Blue and Red CoA, and a corresponding allocation of air and land assets to a set of axes, the Historical Analysis equations are used to assess the probability of immediate and ultimate breakthrough by the attacker, the likely level of casualties, and advance rate. These values are used to check that the current CoA is still reasonable. If not, a new CoA is chosen (corresponding to a different set of axes) which gives an improved outcome. The total available set of axes is assumed fixed in advance, through scenario analysis, and it will also be preferable to select particular 'bunches' of axes as CoA, to take account of factors such as overall force mobility.

c). This assessment is carried out each day by both sides. Each commander assesses the force density ratio on each axis based on perceived force levels, and thus may misallocate forces if his perception is poor, leading to a poor plan.

Genetic Algorithms

The use of Historical Analysis in this way allows a complete Campaign Plan to be very rapidly evaluated in terms of high level measures of effectiveness (MoE) - although currently such Historical Analysis is only available for the land/air domain. The use of Genetic Algorithms to 'breed' a number of plans, and select out those with good MoEs is the next stage of the process. This allows an optimal plan to be formulated at the start of the campaign. As the simulation progresses, the plan is reassessed, using the same Historical Analysis algorithms. If the MoE indicate that the plan is failing, this corresponds to a *key decision*, as described in (16), and a plan repair process can be put in train. This could consist either of a rerun of the Genetic Algorithm (corresponding to adopting a completely new plan) or, less extremely, a search of other neighbouring solutions which would improve the existing plan, through choice of a different Course of Action.

Conclusion

An approach has been described which allows the representation of the Command and Control process in constructive simulation models of combat. The aim is to produce a model of the C2 process which avoids the use of large sets of decision rules. In consequence, this representation will lead to simulation models of combat, with an embedded representation of C2, which are relevant to the post-Cold War analysis environment.

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Reflections on the use of the "RSG-19 COBP report" in C2-analysis projects.

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1. Introduction

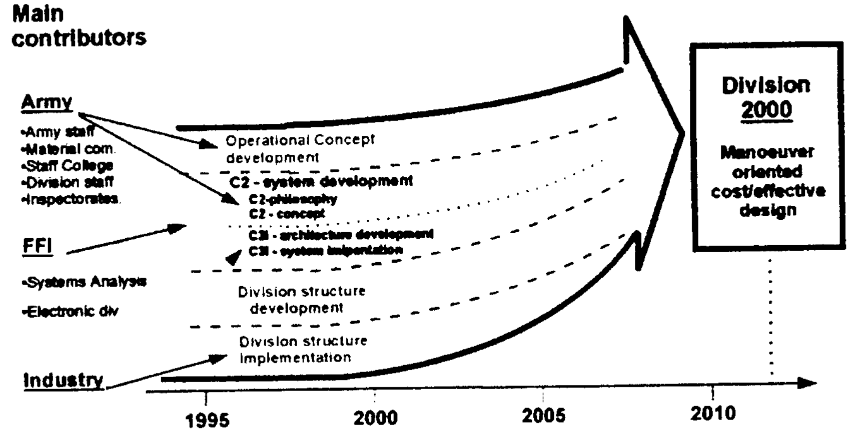
RSG-19 has completed a Code Of Best Practice (COBP) for the analysis and modelling of Command and Control (C2). FFI has recently conducted a major command and control analysis project for the Norwegian Army, and I have asked myself the hypothetical question: How could this project have benefited from a COBP if it had existed at the time when the project started? I quickly could think of several ways in which the COBP could have been useful, but the potential most important one I had not anticipated when I first asked myself the question. As a result of this thinking process I realised that it was not easy to get a clear appreciation of the value of the COBP in relation to a specific analysis. Therefore I thought my reflections on how the COBP may have been used, and speculations on what impact such use may have had for the result of our study, could be of interest to others, in particular those who are or will be involved in similar studies in the future.

Most people making an overall assessment of our C2-project would conclude that the project ended up as a success. However, success is a relative term, and we also experienced serious difficulties during the project of both methodological and project management nature. I have concluded that the potentially most important contribution of a COBP had it existed, would have been to improve the communication within the project team and thus facilitate the project management. This is what I am going to expand on during this presentation.

As a background for explaining how I think the COBP could have been used I need to tell you about the project and explain some of the problems we encountered in the study process.

2. Army C2 analysis project

The C2 analysis project ("Future C2-system for the Army") was part of a development program for a new Army division labelled Division 2000. On figure 1 the complex environment of the FFI-study, and the role of the study in the C2-system development process is illustrated. FFI had the task in co-operation with the Army to produce a C2-system description which should form the basis of the long term development process of the future Army division C2-system. In parallel to the study both the operational concept and the division structure were under revision and development.



<u>Figure 1</u> The Division 2000 development process towards a modernised system in a 20 years time frame. The C2 analysis project at FFI was a central player in this process providing an important part of the foundation of the system. The main contributors and the areas where the FFI project contributed are indicated.

The project started in September 1994 and was completed as planned by mid 1997. It is a large project by FFI standards, manned by army officers and scientists with different backgrounds involving 3 different FFI divisions.

A brief formulation of the stated project objective is: "Support of the Army in designing a new and modern concept for the command and control system of the division, by conducting cost/effectiveness-based analysis of alternative solutions". The Army put a lot of emphasis on the project and postponed several decisions awaiting the result of the study. Hence it was important to finish the project in time for the implementation program to proceed. On the other hand the significance and usefulness to the customer was dependent upon to what extent we were able to reach our ambitious objective. The objective implied that our recommendations should be the result of integrated effectiveness analysis covering the complete C2-system and not only a set of assessment for parts of the system, not linked together.

The Army decided to change to a manoeuvre oriented concept of operation that was not well described at the time when analysis of the C2-concept started. This added to the complexity of the analysis since we could not base our study on well established knowledge, but had to establish a sufficiently precise description ourselves within the project, anticipating the results of the army's deliberations.

At the time, it was well recognised that no established and recommended method for C2-cost/effectiveness analysis existed. Hence, in order for us to conduct such an analysis the following activities were required:

1. Develop alternative C2-concepts and C2-structures to be analysed

2. Develop the cost/effectiveness methodology (included the models to be used in the study).

3. Conduct the cost/effectiveness-analysis and obtain a result.

These activities should ideally have been undertaken in sequence, but the timc ..ailable for the analysis required a parallel development. In other words, we had to develop and refine the analysis as we went along and learned more about the subject we were studying. The problem was so complex and comprehensive that it was vital for the whole study team to contribute in this process.

2.1 Organisation and manning of the project

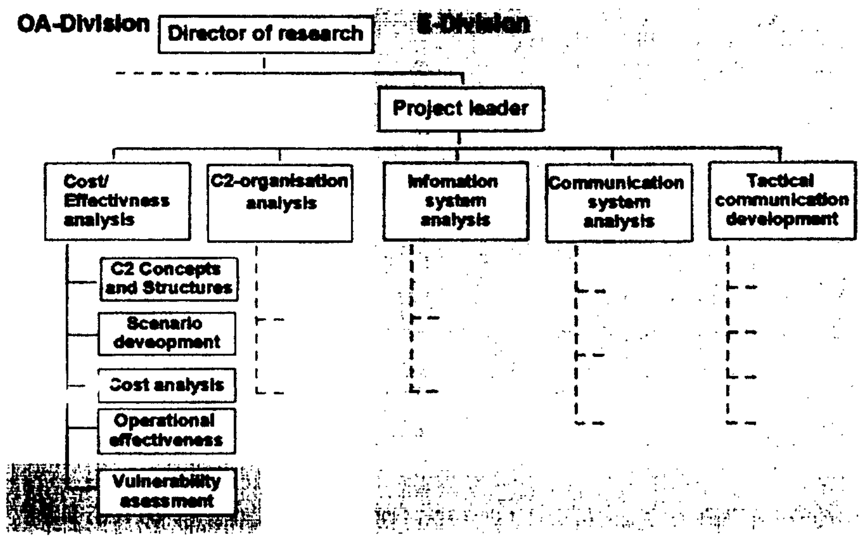


Figure 2 Organisation of the project. The sub-projects is shown together with the activities of the Cost/effectiveness analysis sub-project. For the other sub-projects activities are only indicated by broken lines.

Figure 2 shows the organisation of the project. The project consisted of about 35 well educated scientists (management included), with different backgrounds in mathematics, natural sciences and engineering. Several, were newly recruited from university. About 20% of the personnel originated from the Operational Analysis (OA) -division, of which only 3+ was experienced in OA. The rest of the study team, including the chief scientist responsible for the project and the project leader, had their experience from research and development in tactical communication or information systems. The personnel turnover during the project was 30%. In other words, an inhomogenous team in terms of professional background, little experience, OA- experience in particular, and a relatively complex project organisation.

2.2 The study process

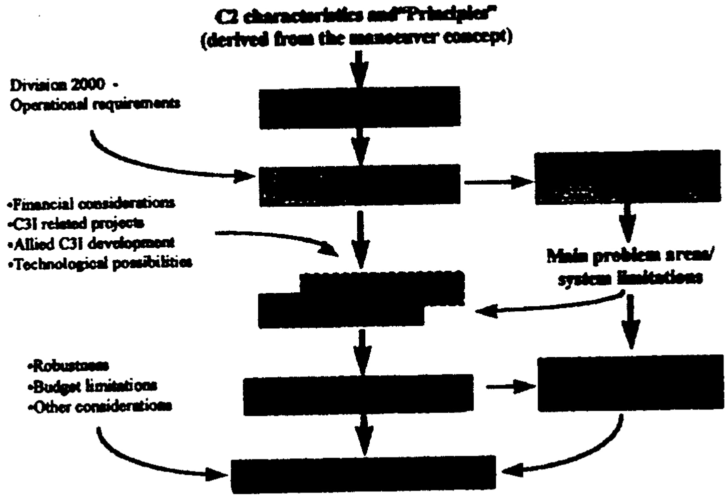


Figure 3 Original formulation of the study approach, indicating the steps from ideas and principles to a recommended C2-concept. An iterative approach each time refining the C2-concept description based on results from analysis.

Figure 3 outlines the study approach chosen in the original formulation . We used other terms than the COBP, and if the approach had been developed today it would have looked different. But in principle the approach would be in line with the recommendation of the COBP. An iterative approach, starting with problems and issues, and ending with risks and uncertainties. I am not going to explain the approach further. The effectiveness method will be presented later in the symposium by Hans Olav Sundfør.

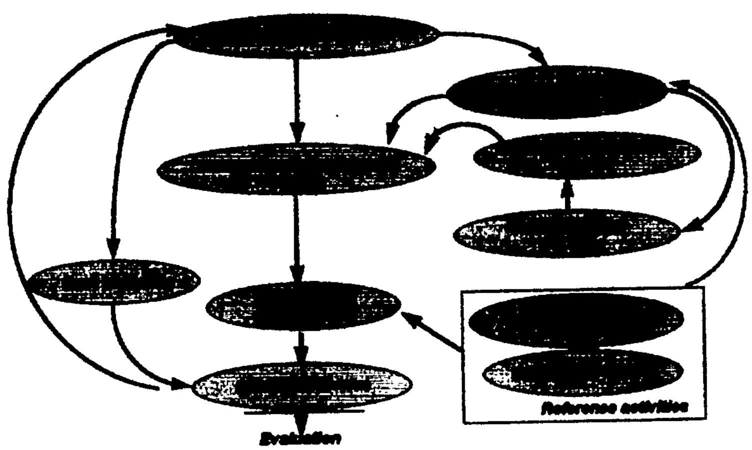


Figure 4 Cost effectiveness method and main activities. The arrows indicates main flow of result exchange necessary to complete the analysis. Arrows pointing in two directions would have been a more appropriate description of the real process, in order to indicate that results had to be communicated both ways for the activities to work in parallel.

To perform the cost effectiveness studies the study team was divided into sub-teams, each with the responsibility for a particular study area. Figure 4 shows the different study areas together with the links necessary to complete the analysis. The idea was that each team should study their area of responsibility and from the insight they gained through these studies provide answers to the questions arising as we moved along. This was a challenging approach considering the complexity of the problem and the lack of OA-experience for most of the study team.

The problem was to achieve a true parallel development in all study areas. Each sub-team had a problem since they did not know exactly the questions they would be asked, but had to seek the information actively from other sub-teams in order to direct their own study activity. Other sub-teams would have to make assumption about the results to be produced by other sub-teams in order to make progress. . Students coming directly from university are in general more happy to solve well defined problems than to be told they are supposed to become the expert on a particular subject and decide themselves how best to contribute to the solution of the total problem. The result was that each sub-team would tend to wait for input from the management or others sub-teams, resulting in close to a "dead-lock" situation. Fortunately this situation was eventually handled in our project.

The key to success with the parallel study approach is to achieve a high level of inter-team communication and a high degree of involvement by each team member. The problem of promoting inter-team communication to the required level and increase the involvement is difficult for several reasons.

Even with personnel with their background in mathematics, natural science and engineering the gap in experience was too large to achieve the necessary common understanding within the team. Added to this is differences in professional culture and interest that seems to have had a substantial impact on the level of understanding, even when a different natural science discipline is the only difference in professional background. For example, operational analysts will, in general, be more ready to accept rough estimates and higher risk for a wrong conclusion than scientists with a more technical background. I believe the COBP could have been used to reduce such communication barriers, as I will come back to.

These problems did not receive the necessary attention at the beginning of the project. The director of research, in his "1. commandment", stated from the start the responsibility everyone on the project had for its success: "If anyone on the project believes the project is not heading in the right direction he/she should tell the management. Statements afterwards like, I could have told you, will not lead to promotion.". In spite of this the problems did not surface during the first part of the project.

In the first year of the study the team management focused their attention on understanding the problem, working out a method for solving it, and starting the model development. The solution process received less attention in the beginning. This may be understandable, because the problem in itself was so challenging, but was in retrospect a mistake. Difficulties of the type discussed above posed the most serious

threat to a successful completion of the project. A small questionnaire study of the project towards the end seems to support this.

The questionnaire was issued to find out how the different members of the team experienced the analysis process they participated in. From the answers it appears that a major problem for many of the members of the study team was to really understand the objective of the project and their role in the study process. In particular the scientists performing the technical analysis, such as analysis of the performance of tactical communication had these problems. This lack of understanding led to frustration and confusion while they awaited input from other parts of the project in the belief that someone must have all the answers.

These problems were discovered in time during the analysis, and a restructuring of the project and other actions were taken to improve communication within the project and the involvement of the individual scientist.

2.3 Result of the study

The method and the process described above proved to work in the end and the project produced the desired result in terms of a recommended C2-concept. This concept has been adopted by the Army as the basis for the development program and implementation of the Army's new C2-system. In this program, further specification of the C2-concept will constitute a consistent basis for the development and implementation phase. The C2-concept together with the project results supporting our conclusions, have the potential to serve as a guidance for present and future priorities, that may be necessary in order to implement the concept or adjust the concept if important assumptions should change. However, the Army would have liked to have a more detailed basis for final prioritisation of their C2-projects, but the time did not allow us to meet such a request, which may have been achieved by a more focused project.

Two factors contributed most to the overall success of our study:

1. The intimate co-operation with the customer in his C2-development process.

2. The integration of expertise from different technological disciplines, traditional military OA, economy, communication technology, information systems technology.

The intimate co-operation of the customer helped us in describing command styles and organisational structures, and formulating and assessing alternative C2-concepts. On the other hand, we acted as catalysts in the design process towards a new C2-concept by bringing forward new ideas, and developing and detailing different concept ideas. When the project ended, this co-operative effort was in particular important for the understanding and acceptance of the results of the study within the customers organisation.

I have already explained the importance of integration of the expertise from different technological disciplines. It was this integration of expertise which enabled us to come up with a complete and consistent analysis as the basis for our recommendations. In my opinion the result had been even better with the integration of a wider spectrum of expertise, for example experts on organisational theory and cognitive science. As I have explained it was at the same time problems of integrating different expertise that caused some of the problems threatening the success of the project.

3. Benefits of the COBP related to the project

In the description above of our C2-project for the Army I have explained our major problems in conducting the analysis and pointed to issues and factors which could have improved the result. The question is now would the COBP have made a difference if it had existed, and how? Following my impression of COBP's main characteristics, possible benefits are discussed related to the project.

The benefit a person will have of the COBP is very dependent on the background of the person. I have therefore sectioned my discussion in three parts. First the experienced OA analyst, then the team management with experienced scientists without OA background included, and finally the whole team.

3.1 Important Characteristics of the COBP

It has credibility, being developed by experienced analysts who have personal experience from C2-analysis.

It is neutral to the project. Not developed in the project, and based on perhaps other ideas and experience.

It is complete in a sense since all the important topics of C2 effectiveness analysis is covered.

It is not too voluminous and can be studied in acceptable time.

To people new in the area of C2-analysis as we were, the comprehensive bibliography and reference lists would also have been useful. Together with the many practical advice on modelling.

3.2 Benefits to the experienced OA analyst

The COBP is intended to be used by the experienced operational research analyst as a guidance for analysis of the C2 component. It is obvious that the COBP would have been useful for the experienced OA scientists on the project. Since we did not have much experience with analysis of the C2-component, studying the COBP would have increased our knowledge about C2-analysis and given us a "flying start" in designing

our study approach. It would have helped us in structuring the problem, we would have been able to sort out important issues early in the process. From the COBP it would have been clearer to us what the difficult issues of the analysis and the modelling were, and we would probably have been more aware of the modelling requirements not met by our current model inventory at an earlier stage of the analysis process.

The COBP does not, however, give a full recipe on how to solve a particular problem. The analysis method must be designed according to the problem to be solved.
In broad terms I believe we would have followed the analysis method we eventually came to use. But a clearer and better description of the method would probably have resulted if the COBP had been available. This is an important benefit, since the method then would have been easier to explain to the rest of the project.

Although the COBP would not have changed the analysis method used in the study, the advice given would have led to adjustments and improved the analysis. I believe the treatment of human factors and organisational issues could be examples of this. Puzzled by how the COBP put human factors and organisational issues as separate items before the scenario and measure of merit, we might have been triggered to focus on these issues earlier. By so improving our own understanding, the vital communication with the customer on these issues would have been more effective.

3.3 Benefits to the team management

As mentioned before the team management was a mix of OA-analysts and experienced scientist without OA background. In the process of designing the analysis method, I experienced that we had some problems in understanding each other at a sufficient level to allow effective in depth discussion and exchange of ideas. It therefore took quite a long time and many meetings to make an analysis method understood and accepted by the project management. I believe the COBP could have facilitated the communication within the team management. If we had started with a discussion of the COBP, this could have constituted the basis for a more effective communication on the OA-approach and the analysis method. One result could have been more time allocated to management problems. The increased understanding would also be a useful basis for scrutinising and improving the method further.

Team composition is an important management task and could have improved results. COBP advice inter-disciplinary teams and explicitly mention specialists in organisational theory. We were also well aware that such expertise might have been useful. However, the composition of the study team was more or less given, and it would have been unrealistic to hire this type of expertise. I think this is a fine example of a good advice which is difficult to implement.

3.4 Benefit to the study team as a whole

The greatest benefit to the project, as I have explained earlier, would be if the COBP could have improved the inter-team communication and increase the level of involvement of each of the team members. Significant effort was allocated to achieve

this. A comprehensive scenario constituted the basis for discussions and for common understanding of the analysis problem throughout the project. The difficulty was to have a document to act as the basis for our communication on methodological problems. I think the COBP could have served this function. It has the important characteristics discussed before: credibility and completeness, and that it is manageable to read. The challenge is to have the COBP well understood by inexperienced scientists. My suggestion is to have worked through COBP with the whole study team guided by an experienced OA-analysts. This would have required the necessary priority and time allocated for this purpose. Then I believe the COBP could have significantly improved the understanding for all the team members of the problem to be solved and the analysis method to be applied. The result would have been an analysis with a better focus on the important problems and less frustration in the team.

In order to impose such a procedure we had to be able to foresee the communication problems we encountered in the project, or become aware of such problems at an early stage. It is unlikely that we had been able to anticipate our problems, but we are now well aware of the threat to an approach based on parallel studies of complex problems.

Example of a possible procedure for use of the COBP in our study could then be:

- Management team designs a first cut on the analysis method with the COBP report available. (1 month)

- Management team studies the COBP together and if necessary revises the method. The main objective being a better common understanding of the method. (A couple of months may be allocated to this effort.)

- In the meantime the rest of the study team should be encouraged to collect as much information as possible about the subject they were likely to study.

- Next the whole study team should have been forced to study the COBP in dialogue with the management team. The idea is that all should have an appreciation of the problems encountered in other parts of the study.

- The procedure should have ended with discussion of the method, involving the whole study team. The COBP would then have constituted a written reference for the whole project in developing the analysis method, enabling the analysts to relate their contribution to the total.

Application of a procedure like the one sketched, I believe would have improved the implementation of our approach significantly, and resulted in a more detailed basis for final recommendations in the Army's C2-project.

The success of the approach described above is dependent upon a considerable effort put into the study of the COBP. In parenthesis I have indicated months. The decision on whether to apply such an approach, or not, would be to assess the time gained against the time spent on the study of the COBP. In our study I believe the approach would have paid off, even if up to half a year had been spent on the procedure.

Other potential benefits from the COBP for the individual analyst would be to use the list of references and some of the advice on modelling on his/hers part of the problem. The value of this should not be underestimated, but in our case I do not think it would have improved the result significantly. Time, for example, would not have allowed us to exploit the recent advances in modelling mentioned in the COBP.

4. Conclusion

As the result of my reflections on how COBP could have been used in our C2-study for the Army I have concluded that the main contribution of a COBP would have been to act as the basis for communication within the project, which in turn, would have saved a lot of frustration and confusion and focused the work, improving both the quality of the study and the quantity of useful results. I have tried to explain and justify this view.

The conclusions are based upon my experience conducting the C2- study for the Army. This study was characterised by a comprehensive and very complex problem which was important to solve within a scheduled time limit. Success was dependent upon our ability to cover the whole range of factors impacting on the design of a future C2-system, in order to end up with recommendation on the full system, rather than be left with a set of separate results not linked together. Consequently, the integration of expertise from different technological disciplines is vital to the success of the project, and a major challenge is to solve communication problems that will arise as a consequence of the integration of expertise. My conclusions may apply to studies with similar characteristics.

I have discussed possible benefits of the COBP from the point of view of a particular study. I believe the COBP would have significantly improved the results of this study. Unfortunately I cannot support this conclusion with actual experience, but hope you have found my reflections interesting.

However, discussing benefits of the COBP report the following closing remark is appropriate. In the broader scope and longer term I believe the COBP document has a very important role to play as a basis for further co-operative development of the methodology and the modelling basis for future C2-studies within the NATO OR-community. Promotion of such a development, following the recommendations and conclusions of the COBP would significantly improve our capability to study problems involving the military C2-process and give the right advice to the decision makers. This last point is a very important one but not the issue of this presentation.

Thank you for your attention.

Command and Control Evaluation in the Information Age

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The advent of the information age is rapidly accelerating the exchange of information between military components. To take full advantage of the anticipated benefits of the information age, the military is being forced to rethink the way in which it conducts business and organizes the battlefield. The greatest impact of the information age will be on the command and control systems and processes, and in how to apply the new capabilities of the information age to increase the speed and quality of decision making.

In order to understand how to improve the command and control process, it is necessary to understand what that process is in its basic form. Command and control can be said to consist of a set of primitive functions. These are called primitive because they have historically been shown to be part of any C2 system regardless of the technology or doctrine applied. The functions consist of those necessary to provide the required information to the decision maker and the command and control processes that enable situation assessment, planning, and execution. The information functions include:

- Seek information
- Retrieve information
- Archive information
- Inform population
- Disseminate information
- Consult with staffs and decision makers
- Report out to staffs and decision makers
- Present information to staffs and decision makers

The information functions enable the command and control processes of:

- Comprehension of the operating environment which consists of the intelligence, surveillance and reconnaissance process (ISR), and fusion of data and information (identify, situation assessment, threat assessment, action assessment).
- Understanding which is a sufficient comprehension of the nature of the situation such that action is enabled
- Decision making which is the process of course of action (COA) development and assessment, uncertainty management, setting of criteria, and prioritizing.
- Decide which is the selection of a course of action and the decision to implement it.
- Battle management which consists of the creation of a plan or replan and the associated implementation orders.

While these functions and processes will not change, the speed at which they are performed and the ways in which they impact the decision making and execution process will change. The challenge is to understand how the information age provides opportunities to make the processes more efficient and effective.

A way to describe the current command and control process is to view the command and control mechanism as a system seeking to attain adaptive control over its

environment[1]. Adaptive control is defined as being able to adapt ones plans and actions to predicted changes in the environment so as to maintain control over that environment. In order to be effective, this control system must monitor its environment, develop an understanding as to what is happening, develop and assess course of action to control the environment, predict the consequences of selecting a course of action, decide on a course of action, develop a plan, and provide direction to subordinates, and then monitor progress. In a military situation the environment consists of friendly, enemy and neutral forces (including non-combatants), terrain, and weather, all in the context of the mission to be performed. This control mechanism can be displayed as a feedback cycle as shown in Figure 1.

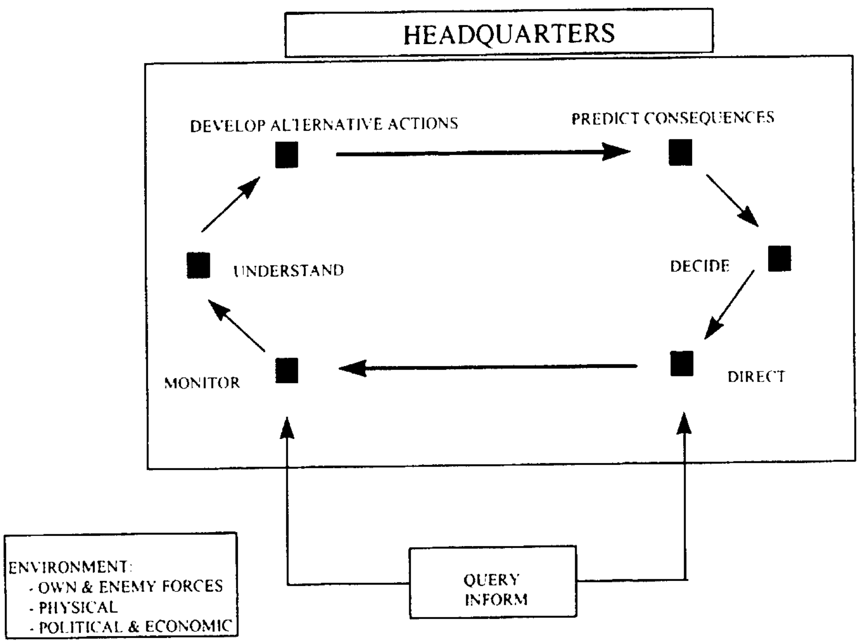

Figure 1 Command and Control Cycle

The advent of the information age is causing us to rethink this cycle. Figure 1 can be recast as a set of spheres, as shown in Figure 2. Monitoring and understandings of the situation are located in the Battlespace Visualization sphere, alternative courses of action, predictions, decisions, and plan development are part of the Decision Making sphere, and direct, disseminate and execute are in the Battle Management sphere, with information providing a linking mechanism between the spheres.

Figure 3 shows the information "grid" maturing, with information becoming ubiquitously available to all levels simultaneously. As the information grid matures, it begins to draw the spheres together, creating interesting conjunctions and intersections. Decisions are now generated in different domains depending upon the nature of the decision. Complex decisions, requiring complicated and thorough analyses of courses of action and available options, continue to be part of the decision making sphere. Contingent, or simple, decisions, which are those requiring only that the commander (staff) understand that the situation matches a planned contingency, occur at the intersection of the Battlespace Visualization and Battle Management

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[1] Hayes, Dr. Richard E, Mark Hainline, Conrad Strack, and Daniel Bucioni (1983). Theater Headquarters Effectiveness: Its Measurement and Relationship to Size, Structure, Functions and Linkage. McLean, VA: Defense Systems, Inc.

spheres. The reduction of uncertainty resulting from the vast improvements in information availability will allow many previously complex and/or contingent decisions to be automatable decisions (e.g., target/weapon pairing). They occur at the intersection of the three spheres and are characterized as rapid, pre-planned, and requiring no human intervention.

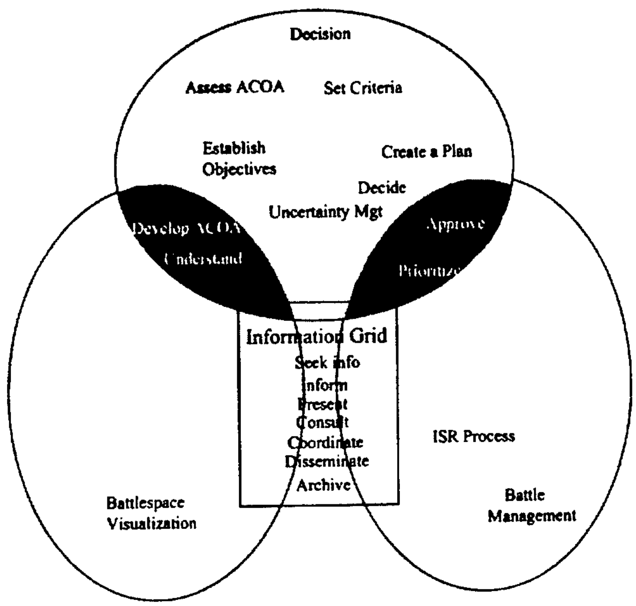

Figure 2 C2 Functional Spheres

This new way of operating will alter drastically the way we do business. Achieving military superiority in this context will almost certainly require changes in organization and doctrine. Assessments are required not only of the capability of proposed material acquisition to achieve the vision, but also of the ability of new organisational schemes and doctrine to support the new operational concepts. Leaders need to understand how to operate in an environment where information is universally available and command and control is governed by new paradigms. The personnel that operate in this environment must be capable of independent action based on their view of the situation.

The lesson is that, when assessing progress, all three domains need to be viewed in the context of an integrated and coherent whole. We need to evaluate the whole and not treat the piece parts individually as we have in the past.

Assessment of C2 in this environment presents a new challenge. We need to understand how the postulated changes affect our assessment practices. One approach to doing this postulates those differences likely to occur between today's command and control and future command and control, and then describes an evaluation methodology to measure the impact of the changes.

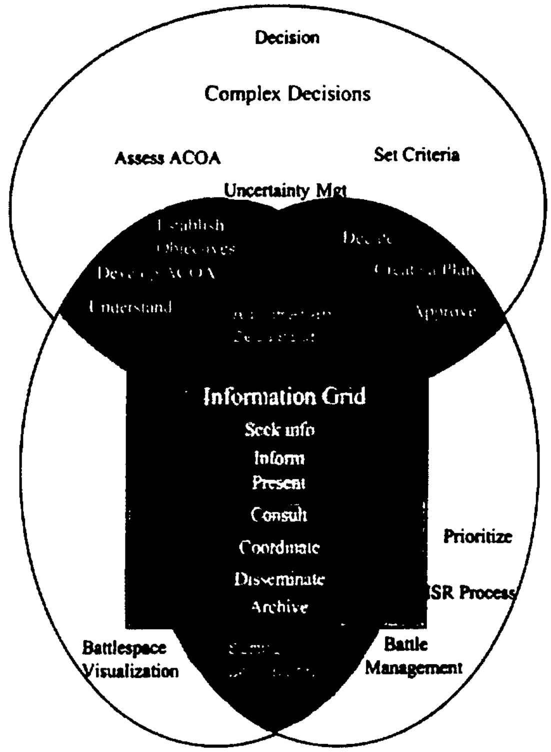

Figure 3 C2 Functional Spheres Linked by Information

The foundation for the methodology is an understanding of how the future command and control environment is expected to differ from today's command and control environment. These differences can be said to occur in five broad areas: Better battlespace visualization, more adaptive decision making, more agile battle management, information enabled organizations, and significant increases in force effectiveness and efficiency.

The catalyst for these improvements will be the advances in information and information processing technologies. Information technology will enable a significant improvement in Battlespace Visualization. This means that commanders and staffs will have access to information that is complete, current and consistent and is understandable by the recipient. Commanders and staffs will have unlimited access to the information in the desired format at the desired time. They will be empowered to explicitly consider future events in the battlespace. The high fidelity and completeness of the information available will enable the commander to explicitly manage uncertainty through reduction of the unknown and greater confidence in the known.

Improved battlespace visualization will enhance the capability for adaptive decision making, where decisions will be made much more quickly in the context of the complete battlefield situation rather than fragments. The commander and staff will have decision aids with imbedded predictive capabilities leading to development of multiple courses of action and plans rich in contingencies.

Battle management will be agile, that is, the ubiquitous nature of the battlespace information will allow continuous consultation and coordination, which, when coupled with a highly responsive ISR capability, will provide a continuous, merged plan and execute capability. Units in the field will be self-synchronizing, with the capability to conduct coordinated operations without the need for central direction.

The result of these improvements will be the creation of information enabled organizations, characterized by virtual teams that are established and disestablished as the situation requires, and distributed information and work processes. Command will be decentralized as a result of the information and communications available to subordinate organizations.

Battlespace Visualisation

Better battlespace visualisation is accomplished mainly through the provision and display of information leading to improved understanding of the situation The information provided to users will need to be complete including all relevant information of importance to the user with associated uncertainties (e.g., confidence levels). The information must be provided in time for the user to take appropriate action and must be more accurate than today's standards. The information should be precise to the degree of the user's capacity to consume that level of precision. There are various elements that characterize the degree of precision for a user including the bandwidth and time required to collect and transmit that degree of precision, the targeting requirements of a weapons system, and the desired degree of aggregation.

Information must be consistent across all command centers and echelons, across all functional areas, and over time. The exchange of knowledge will include understandings of the situation, projections as to the future state of the battle space including possible emergent situations, possible alternative futures and their associated uncertainties.

The information strategies necessary to provide the required degree of data, information and knowledge will require a balance of information push and information pull philosophies that both ensure that all requests for information are satisfied but also ensures the provision of information not requested but of importance to a user. The vast amounts of information available and being transmitted across the battlespace will require the employment of adaptive bandwidth strategies. These strategies will likely include tradeoffs between computational and communications capacities. For example, should "raw" data be provided to the user for analysis or should the user be provided with analyzed data (information)? The former requires a greater communications capacity to transmit large quantities of data to each user, the latter imposes a large central computational capacity.

Adaptive Decision Making. - Decisions can be broadly sorted into three types: Complex, Contingent, and Simple decisions. Complex decisions involve the maximum degree of senior officer involvement and require the specification of alternative choices, criteria, and/or method(s) for selecting courses of action. They are characterized by the environment in which they exist. The components of the decisions cannot really be quantified and their results not easily anticipated. Complex decisions will generally require extensive consultation and coordination with data and

knowledge garnered from a broad range of sources. Contingent decisions are those whose actions are appropriate if the context falls into different, recognizable situations or patterns generally in the from of "if this happens then do this". Information will enable the linkage between plan contingencies and the picture of the battlespace that provides the immediate recognition of the indicators for activation of the contingency. The amount of consultation will be considerably less for contingent decisions than for complex decisions, because once the contingency is recognized, appropriate action can be taken without recourse to higher authority. Simple decisions are those where the correct action is knowable algorithmically, rule-based, or from pattern matching. The "simple" decision is one that requires little human processing. Once the phenomena is observed an action can take place in a near automatic mode. As noted by Gary Klein[2], in this situation, to understand is to decide. The challenge is to identify this set of simple decisions and convert an ever increasing number of them to automated decisions. An example of this can be seen, in certain situations, as removing the human from the loop by directly linking sensors to executing platforms.

One of the major areas of interest in the maturing Information Age technologies is to relieve the decision maker and his staff of the simple and compound/contingency decisions and provide both the time and energy to address the complex.

Agile Battle Management. Agile battle management is characterised by a merged planning and execution process and integration across echelons and functions and over time.

Consistent battlespace understanding and real time consultation and coordination between elements will enable a continuous, or merged, planning and execution process. Planning will be constantly updated by information from the battlefield and changes to plans will be immediately available to those responsible for implementation/execution.

Integration across command echelons and also across functional domains (e.g., operations, intelligence, logistics) will be accomplished through the elimination of current "stovepipe" information and command flows. This integration is enabled by:

Transparent Access to consistent data and information - Data and information must be available to elements as required. The data will be aggregated to the level appropriate to the user with the capability to drill down or aggregate up as desired. While the information displayed at any element will not necessarily be identical or, common, to that at any other element, it will be based on the same data. All users need "user friendly" access to the data without the need for understanding equipment procedures or protocols. The key phase here is "common and relevant picture" of the battlespace scaled to their level of interest and tailored to their special needs. The relevant information should be accessible to all levels of command and staff

Seamless Communications - Communications paths should be automatically configured without the need for the user to understand or know the path over which the data travels. These paths will be robust, existing in multiple environments: ground, air, low earth orbit and deep space.

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[2] Klein, Gary Sources of Power pp 24, The MIT Press.

Consistent Understanding of the Operating Environment. - The connectivity and data access necessary for all elements to develop accurate and timely situation and threat assessments must be available. All elements will have the capability to share their understanding of the situation in near real time. Collective unit images will form a battlespace picture versus a rigid framework of battlefield geometry—phase lines, objectives, and battle positions.

Merged Planning and Execution Processes - Sensor to shooter connectivity that also connects to the command elements will facilitate almost simultaneous planning and execution across the mission planning and execution continuum. Future forces will possess the capability to achieve multiple operational objectives nearly simultaneous throughout a theater of operations. This simultaneity, coupled with near-real time military and public communications, will blur and compress the divisions between strategic, operational, and tactical levels of war.

Integration Over Time. The integration of echelons and functions includes integration over time. Consultation and coordination must be accomplished in near real time in order to achieve the necessary degree of simultaneity. Units will have the capability to update all databases and the information at all elements in a near simultaneous manner. For example, if new data is obtained, this data should appear in all relevant databases in near real time, and the information based on the analysis of this data should be available to all required users at the same time it is made available to the primary user or requester of the information. Changes in the plans, and the situation and/or threat assessments will be immediately available to all necessary recipients.

Integration over time, in addition to simultaneity, also applies to integrating the past, current operations, and future planning. Intelligent agents that can seek out the relevant information to ensure the continuity of the planning process is one way of achieving this. By enabling decision makers to understand how the situation evolved, what the current options are, and the future projections, a richer set of contingencies can be developed.

Integration With Partners. - Future conflicts and/or crisis situations will likely involve the US with partners. These partners can be military (allies or coalition), international organizations, other US agencies, non government organizations, private volunteer organizations, or foreign government organizations. Each type of involvement will bring unique integration problems - what information to share, how to transmit and receive it, how much integration with command centers is acceptable and/or possible? Provisions need to be made for information sharing over a wide range of possible scenarios, including pre-hostility conduct of field training and command post exercises, and simulations.

Information Enabled Organizations Information Enabled Organizations will be characterized by_integrated virtual work processes. Multi-media links between all echelons and functional elements will allow real time consultation between elements, regardless of geographic location or organizational component, and provide split basing and reach back capabilities. This flexible organizational capability will facilitate the provision of a continuous thread from the overall strategy, through the operational decisions, to the tasks necessary to accomplish the mission. The links

must be flexible enough to enable the organizations to change their composition as the situation and/or task demands.

These integrated work processes will provide the impetus for information enabled units capable of self synchronization and handling simultaneous tasking. This will result in the capability to conduct military planning and execution in an entirely new way. Task organization of military units will be dynamic and mission dependent. This will alter the command structure and the degree of centralization of control. On scene subordinates will have a complete understanding of the concept of operations and the commander's intent, along with a full understanding of the situation, enabling them to take action without the need for commands from above. The degree of control employed will change with the situation, with some situations (e.g., missile defense, decisions with large political ramifications) requiring more centralized control. The challenge for future military operations will be to implement the required degree of control based on the situation

Measures of Merit

The assessment of command and control is generally an assessment of system performance, the attributes of the information provided to decision makers, time to perform C2 functions, the value of information and information processes to quality, and timeliness of decisions, and progressively to overall force effectiveness. We are here primarily concerned with the attributes of information and its value to the decision maker and time functions. As argued by Drs. Hayes and Alberts[3], information includes factual data, information capture, storage and selection, and the integration and interpretation of information. Information attributes generally fall into the categories:

Completeness	Consistency across nodes
Age of the information	Correctness of understandings
Accuracy	Correctness of predicted consequences
Timeliness	Fidelity of directives to decision made

In addition to information attributes, time is a major factor. Time measures have two dimensions; speed and timeliness.

Speed is the time taken to perform a task, such as time taken to complete a decision cycle, or the time to pass information from place to place. Timeliness is information provided in sufficient time for an action to be accomplished. Speed is not generally an unmitigated good - timeliness can be much more important. For example, the ability to provide the right information at the right time is of considerably greater value than the wrong information as soon as possible. Often, trades are necessary between speed and quality of information. Clearly, information that is 75% correct provided in time to take action is better than 100% correct information received too late.

Decision quality, and therefore, the value of information to the decision maker, is assessed by examining the impact of information on the decision and the effectiveness

[3] Alberts, Dr. David S, Dr. Richard E. Hayes, Command Arrangements for Peace Operations pp. 108, 109, National Defense University Press

of the plan. The planned actions are compared with what actually occurred (ground truth). Also the speed of decision making is compared with the rate of change of battlefield events (i.e., can the decision cycle keep up with the pace of battle?).

The future measures of merit will include many of the measures currently in use, however, additional measures are required to assess the benefits of the new information technology. These measures will include:

1. Information measures focused on the provision of a common operational picture and the use of information to reduce uncertainty.
2. The ability of decision support systems to aid in adaptive decision making and reduce the time to complete the decision process.
3. The ability of decision makers to recognize patterns and state changes in the environment.
4. The intelligent application and distribution of information to allow units to task organize as necessary and to self synchronize as the situation dictates. Information enabled organizations.
5. The capability to merge the planning and execution process (Agile Battle Management) wherein execution becomes part of the process.
6. The ability to accomplish missions by massing effect instead of forces.

The following tables contain proposed measures for the assessment of future command and control:

What's Different—Measures of Merit

Better Battlespace Visualization	**Measures of Merit (MOM)**
More complete, current and consistent	• Completeness with respect to commander's requirements • Age of information • "Timeliness" of information • Accuracy of information compared with ground truth • Fidelity of information node-node
More comprehensible	• User understands the information • Compare utterances with ground truth
Flexible retrieval and presentation (pan, zoom, associate)	• Accessibility of information—all nodes have access to needed information • Time required to access information
Future explicitly considered	• Prediction time
More explicit uncertainty management	• Incomplete information is "flagged" • Information is provided with "confidence" tags (compare confidence ratings with ground truth) • Decision aids present adequate options
Information Enabled Organizations	**MOM**
Virtual teams	• Number and variety of participants and locations • Percent of tasks worked at multiple locations
Agile organizations	• Frequency of recognizing need for task reorganization • Time required for task reorganization
More distributed information and processes	• Percent of organization on line, "up time," and volume of information available

What's Different—Measures of Merit (cont.)

More integrated across function, level of command, and time	• Time to consult, coordinate and approve across functions, levels of command, and time into the future • Age of information • Query response time • Percent of data used relative to data at work sites
Improved organizational learning	• Time to recognize patterns and changes thereto • Accuracy of pattern recognition • Time to adapt to changing patterns • Time to create new patterns through innovation • Increased inputs to decision process
Adaptive Decision Making	**MOM**
Context driven decision processes	• Correct recognition of state change • Speed of state change recognition
Imbedded, predictive decision support	• Capability of decision support tools to generate and assess alternative futures and COA
Rapid plan/re-plan capability	• Decision time for implementation of plan changes. Were the plans implementable? • "Goodness" of plans—need for change outside of contingencies • Correctness of predictions
Contingency rich COA analyses and plans	• Number of contingencies analyzed • Number of contingencies built into plan • Were contingencies adequate—e.g., when a plan had to be changed did contingencies cover?

What's Different—Measures of Merit (cont.)

Agile Battle Management	**MOM**
Distributed, integrated, and more simultaneous coordination and consultation	• Number and variety of participants and locations • More correct decisions on complex problems • Time to respond to requests
Highly responsive ISR capability	• Increased self-tasking • Time to respond to tasking • Reduced unsuccessful tasking
Near simultaneous asset tasking	• Time to implement tasking
Significant Increase in Force Effectiveness and Efficiency	**MOM**
Seize and maintain the initiative -Shape the battlespace	• Commander predicts future alignment of the battlespace • After plan implementation and execution, friendly and enemy forces are aligned as predicted • Percent planned high value targets destroyed within plan timeline • Percent designated areas controlled within time specified
-Phase the campaign	• Phase changes recognized • Plan provides logical sequencing for campaign • Sequencing is accomplished as planned
-Control the pace of the battle	• Friendly informed decision cycle shorter than enemy decision cycle • Plans are proactive, requiring enemy to react

What's Different—Measures of Merit (cont.)

Significant Increase in Force Effectiveness and Efficiency	**MOM**
Kill the right targets -Less lethal battle space and less collateral damage -Shorter duration -Increased adversary "Shock and Awe"	• Overall casualties reduced • Unintended targets damaged/total targets damaged compared to a baseline • Time to complete comparable operation (compared to a baseline) • Behavioral impact of fires and threats on organizations, operations, plans and individuals
Concentration of effect replaces concentration of forces	• Compared to a baseline for the same mission friendly forces have greater dispersal with equivalent fire effectiveness
More efficient use of communications and logistics systems	• Percent reduction in bandwidth required (compared to a baseline) • Percent R3 (Right Material, Right Place, Right Time) delivered (compared to a baseline) • Percent supplies, material lost enroute
Accomplish mission with minimum casualties	• % friendly overall casualties compared to a baseline • % critical territory captured • % planned mission accomplishment

Conclusion. Changes in information technology are causing several major changes in the way military forces organise and fight, leading to changes in command and control procedures and organisation. The C2 analyst must understand the nature and impact of these changes when conducting assessments of C2 procedures and/or systems.

THE ROLE OF C3I IN FIELD ARTILLERY SIMULATION

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1. INTRODUCTION

In the years 1997 and 1998 the simulation model SMART, which stands for Simulation Model ARTillery, to support the Dutch army in decision making. Main goal was to derive the optimal number and type of Howitzers, and organisation of batteries and platoons in a battalion. Two scenario settings were used to evaluate the performance of the field artillery system. In the first scenario a division appearance in a general defence task (full war) was simulated. In the second simulation a scenario of a brigade in a Peace Enforcing scenario was analysed. In the model the following components were explicitly modelled:

- Detection resources
- Command and Control cells
- Fire units
- Units of the enemy

In this model the enemy is modelled as a black box and the actions of own forces do not influence the operations of enemy troops. As a consequence damage to own facilities was modelled as a parameter and only inflicted a possible damage after each round of fire.
In this model the Command and Control structure is inflexible. Networks and lines of communications are hard-coded and require a major adaptation in the model when changed.
In the near future specific research questions of the Dutch army are expected concerning the Command and Control structure and lines of communications in the field artillery. We expect SMART to be not flexible enough to support these research themes. Therefore the decision was made to build a new research tool called SMARTER (Simulation Model ARTillery Extended and Revised)

This paper consists of 5 chapters and is build up as follows. In chapter 2 the goal of the tool will be described. In chapter 3 we will describe how we think SMARTER can be used in a scenario setting. Chapter 4 will describe the elements, processes and measures which will be implemented in the tool SMARTER. In chapter 5 this paper will be concluded.

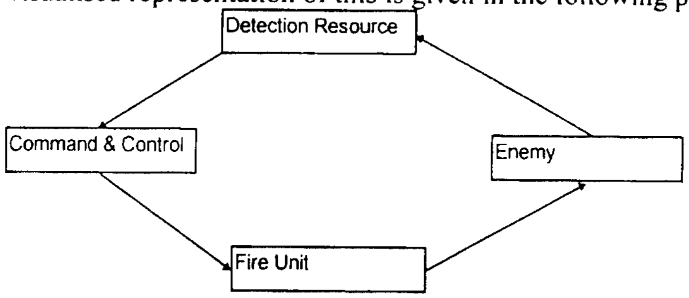
2. GOAL SMARTER

As mentioned in the introduction several research questions from the Dutch army concerning the field artillery system are to be expected. These can vary from the number of howitzers in a battalion, unto questions concerning the optimal organisation structure in which detection resources, C2 and weapon systems work together to optimise the total system.

At this moment the organisation of a brigade is given and all target information generated from several detection resources will, with no exception, be sent to the Deep battle cell of the brigade. The question is whether this is efficient. Furthermore one might want to research which routes have to be followed before a target detection is translated into a fire mission. In the current model (SMART) it seems that the communication resources have great influence on the overall system performance. At this moment communication is not modelled in SMART. In SMARTER communication will be modelled explicitly to be able to investigate the (requirements)concerning the communication resources.

It depends on the specific research question, to what detail the elements of the field artillery system have to be modelled. Our goal is to build a simulation tool that makes it possible to

implement in a simulation model in a fast and efficient way, which can be used to simulate a wide variety of field artillery systems, using various resources in different scenarios. In general the elements: Detection resources, Command & Control, Fire Units and a representation of the enemy are needed to be able to represent to most abstract form of the field artillery system. A visualised representation of this is given in the following picture:



3. HOW SMARTER WILL BE USED

3.1 introduction

To be able to evaluate the effectiveness of a field artillery system, the system has to be placed in an operational context (= scenario). In this scenario weather conditions, terrain conditions, the enemy and its capability, and the own organisation have to be defined. In general it is not easy to define a realistic scenario which can be used to evaluate the system.

This problem is not specific for the field artillery system, but for all systems in which the effectiveness of systems, in an operational setting are evaluated. In general the use of scenario's is a matter of discussion when evaluating the results of research models.

Because of the lack on scenarios, TNO-FEL and the Dutch army started the project "scenario development for policy research". In this project the goal is to develop a set of scenario's, which can be used both by TNO as well as the Dutch army, for both OR studies and policy studies.

This project started in the October 1998 and will probably produce the first scenario in the spring of 1999. When the result of this pilot project will be satisfying for both parties, the project will be continued the coming years to produce a database of scenario's which can be used in all OR and policy studies of the Dutch army and TNO.

In the project "scenario development for policy research" a distinction is made between operational and model scenario's. An operational scenario is a problem dependent description of a future (fictive) situation (starting point) and a hypothetical series of events from this situation (development) leading to an endstate. This description concerns the operational input of a part of the Dutch army.

A model scenario is a set of parameters belonging to a (simulation) model. These parameters describe the starting point in the (simulation) model and the development in time. The model scenario will be based on a specific operational scenario.

3.2 Two sided scenario's

In SMARTER the goal will be to be able to evaluate the performance of own troops as well as enemy troops. The reason for this is to be able to observe the damage to own artillery

components as a result of enemy fire missions. When different types of fire units are compared, the mobility of the fire units can be a major difference. The mobility of a fire unit can be of major importance in surviving a battle and as a consequence the infliction of damage to own fire units has to be modelled more sophisticated compared to SMART. The infliction of damage to own fire units is a result of the operations of the enemy. Therefore the operations of the enemy have to be simulated in detail.

A spin off of modelling both own troops and enemy troops is that in one simulation run, both a defence and an attack can be analysed. In this case the enemy has to be modelled such that it can represent own troops. Also several decision rules can be evaluated when these rules are not the same for both parties.

We will not implement the possibility of more than two parties in a conflict. The reason for this is that the scope of smarter in general will be the total field artillery systems. Even if there are more parties, e.g. a peace enforcing scenario in which multi national forces operate together against one enemy, we will consider the multi national forces as one party in the conflict.

3.3 Scenario's for SMARTER

As mentioned in chapter 2 the specific research questions determine the level of detail which will be used for the different elements. When tuning the system, i.e. the relevant numbers of resources needed to operate optimally, a detailed description of both sides and elements will not always be necessary.

When fine tuning is done this can be evaluated with use of a description of a detailed scenario. When both the project SMARTER and the project "scenario development for policy research" will be realised in time, we will be able to use the same scenario. This scenario will be used for evaluating the whole system.

4. CONSTRUCTION OF SMARTER

4.1 User interface

Before any result can be generated and analysed from a simulation model this model has to be defined, implemented and run. To facilitate these four steps the user interface of SMARTER will consist of four units. These units are: definition unit , scenario builder, simulation unit and analyser.

The definition unit will be used to define the different standard elements in an artillery system. It will be possible to define the elements and save them so they can be used in several different studies without redefining standard elements. Examples are: a fire unit, detection resources, communication network settings and specific C2 cells.

The scenario builder will facilitate the user to implement a scenario with use of the elements defined in the definition unit. The scenario builder will have a graphical user interface in which a terrain will be displayed and units can be placed upon this terrain.

When a scenario is build, it can be simulated with the simulation unit. One can choose several modes in the simulation unit like single step simulation, and batch simulations. Single step simulation will be used to verify the implemented scenario.

The results and data generated during the simulation can be analysed using the Analyser. In this analyser one can interrogate specific elements used in the scenario, as well as display several predefined tables in which several Measures of Effectiveness (MOE's) can be shown.

4.2 Model elements

4.2.1 Communication:

As mentioned in chapter 2, communication resources can be the bottleneck in the field artillery systems. Therefore communication will be modelled explicitly in SMARTER. We consider communication as a technical resource that can be used to transmit information from one unit to another. In this process from sending and receiving we will not take misinterpreting and other noise as a human factor into account in this model. Communication will be facilitated the use of: Communication resources, links and networks.

We will model communication resources as resources in which messages can be inserted and transmitted through a network. It depends on the type of communication resource and type of network used, whether it is possible to queue messages.

Links are the lines used to transmit messages from one communication resource to another communication resource. This can be a physical line between two units or a frequency used by a set of communication resources. A connection will have a length and as consequence a performance based on length and weather and terrain conditions. Based on probability functions a message will be transmitted correctly or not.

A network determines whether one or several message at a time can be sent. We will consider the protocols CSMA (Carrier Sends Multiple Access) and TDMA (Time Division Multiple Access). These protocols determine if a message can be send at the same time someone else is transmitting data and will determine the minimum amount of time needed to transfer the data through the network.

At this moment this level of detail will be sufficient. If a more detailed representation of communication is needed it will be possible to make use of more sophisticated communication simulation tools as a plug in. For example simulation models implemented in OPNET could be used.

4.2.2 Command & Control (C2)

Command and control on its own has a great complexity. We will not model the internal command and control processes in a command and control unit in detail for the reason that the goal of SMARTER is not to optimise the command and control, but the field artillery as a system. In this system we consider command and control as a resource represented in a command post. However we recognise the need of flexibility in building artillery models concerning the Command and Control. To be able to have enough flexibility in SMARTER, we used the following ideas in the modelling the C2 components in SMARTER:

1. In general C2 components are elements in the model, which transform received information in new information and use this information to make decisions. We think of information as messages that are send to and received by C2 and other elements. In the conceptual model we have recognised a boundary set of messages which can be send to a command and control unit. Each message will start a decision routine. The decision routines will be defined by

"expert systems", in which the decision rules will be determined by several parameters. These parameters will generate the needed flexibility in the modelling of artillery systems. Some of these parameters are the a priori priority of targets, the maximum time between target detection and fire mission etc.

2. Decisions can be translated in orders or requests and will be communicated with other elements in the model.

3. Any C2 component has one or more resources, which can be used to concurrently process information. Delay times will be variables, which can be put in as a parameter for each decision routine to be made.

4. C2 components will have one ore more separate resources for sending information through the communication network. So communication will be a restricted resource in a C2 component, but will have no influence on the time needed to make decisions. The number of communication resources and the number of operators will be separate parameters of the model.

5. We do not recognise C2 elements as known staff elements. Any C2 element will be able to make its own decisions, based on the received information and the units connected to the C2 element. For example: Suppose one set of used detection resources are Remotely Piloted Vehicles (RPV) organised in one company. The RPV company will have a control station which interprets the information generated by the RPV. This control station will only be able to decide to generate a target detection or not. Because no other information is transferred to this control station, no other decisions can be made. On the other hand a C2 component, which has only connections with other C2 components, will never be able to give orders for a fire mission, because it has no fire units under its command. This C2 element will only be able to give fire requests to other C2 elements, which have fire units under their command.

When these ideas are implemented, we are able to answer a wide variety of research questions. Examples of these questions are:

- How to choose High Pay off Targets (HPT's)?
  In the targeting process, decisions have to be made which targets to fight,how these targets to fight (suppress, neutralise, destroy) and when.
- What ammunition is the most effective?
  As mentioned before it is not always necessary to destroy a target. So different types of ammunition can be used to reach the goals of the artillery system. The choice which ammunition to use in which situation is a typical C2 decision to be made.
- When the decision is made to engage a target, one or more fire units have to be chosen to execute the fire mission. Which fire unit(s) to choose and how many depends on several factors. By varying the parameters of the C2 element, different strategies can be evaluated.
- The time needed to take a decision will depend on the information available in the C2 element and the number of C2 elements used in the decision routine. (See also paragraph 4.2.3). Completion times can be of great importance in the field artillery system and thus will certainly be a subject of research in the near future.

4.2.3 Information systems

Decisions made in a C2 cell are determined on the information available in the cell. If this information is not available a request for the needed information has to be made. Whether

information is available or not is determined by the used procedures in the field artillery system. These procedures can be facilitated with information technology (IT). Based on the procedures and implemented IT the C2 cells will have or have not specific information. In SMARTER the implemented IT determines which procedures are followed and how information is distributed among the units.

At this moment the Dutch artillery has the VUIST-1 system. In this system all units within a brigade are subscribed to the network and have information derived from the same basis. Studies are performed to introduce the information system VUIST-2. In this system information is the same from battery till division level. VUIST-2 also facilitates the automation of decision rules like transforming a fire request to a fire mission for a specific fire unit.

If decision rules are automated, decisions will be made much faster and thus C2 cells will be relieved. On the other hand this requires a regular update of all needed information and therefore the number of messages will increase and can cause congestion in the communication networks.

4.2.4 Fire units

In SMARTER the smallest units that are able to deliver projectiles will be fire units. A fire unit is a number of weapon platforms with their weapon systems and ammunition. Usually a fire unit will have the size of a platoon. We chose this approach because in Dutch artillery the doctrine is that all units in a fire unit will work together at the same time on the same fire mission.

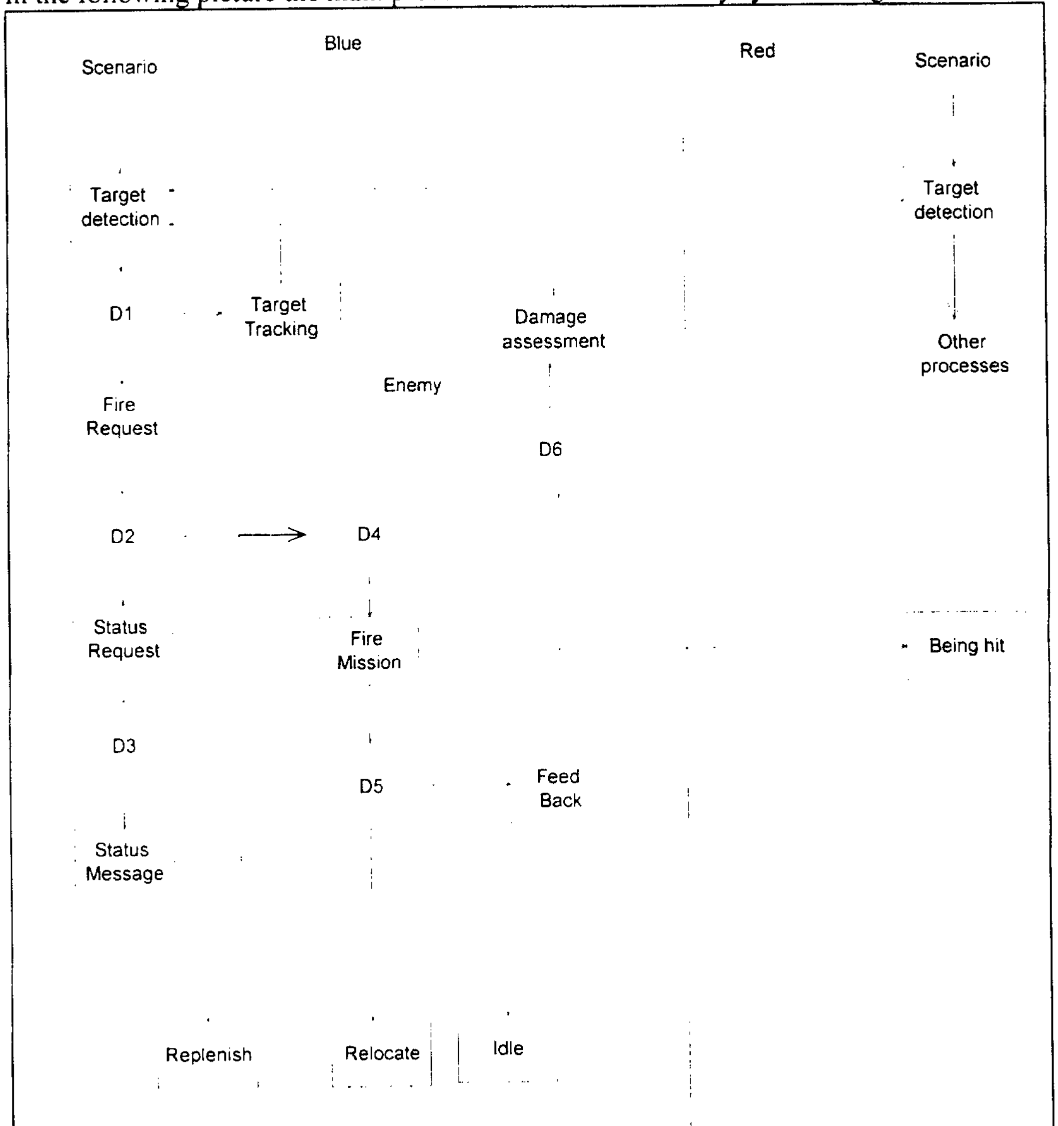
If necessary a fire unit can be modelled as a single platform and this makes it possible to analyse models in which every single platform is modelled. In general one fire unit will receive one fire mission to execute. When a target is too large for one fire unit, the decision can be made (C2 component) to synchronise the execution of a fire mission between two or more fire units.

4.2.5 Detection resources

SMARTER will provide the use of several types of detection resources. These can vary from forward observers (FO) to more technical sophisticated equipment like RPV's. Any detection resource will be able to generate target information. Based on the technical possibilities, detection resources will be able to "see" a restricted range of targets. Detection resources will be used for target detection, damage assessment and target tracking.

4.3 Simulated processes in SMARTER

In the following picture the main processes of the field artillery system are given:



As shown in the picture there are a number of decision processes in the C2 cells. The decision processes of the C2 elements are components of the so called "OODA" loop, which means Observation, Orientation, Decision and Action. In this context, observation is a process of the detection resource. Action is the process "Fire mission" of the fire unit. The decision processes are:

1. Evaluation target detection
   When a target is detected, the decision has to be made whether this leads to a fire request or not. This decision can be based on the observed activity of the target, the initial priority of

the target and - if measurable - the threat of the target. When the decision is made not to engage the target, one can choose to file the target detection and ignore the target, or one can give the order to track the target and wait until the activity of the target changes and a fire request / fire mission is more opportune.

2. Evaluation fire request
When a C2 element receives a fire request several decision have to be made. First if the C2 element has fire units under its command, the decision can be made to engage the target or to give the feed back that a fire mission is not possible at this moment. If this is not the case, the C2 cell can try to find another C2 element to pass through the fire request or return a message that a fire mission is not possible. Which decision is made, depends on the availability of fire units, the time remaining the target has to be fought, ammunition stock etc.

3. Evaluation status request
The decision process "evaluation fire request" will depend on the status of other units. If this information is not available at the C2 cell, this information has to be gathered from the unit. This unit evaluates this status request and produces the information needed.

4. Second evaluation fire request
When extra information is received at the C2 cell, the available extra information can be used to decide whether to fight the target or not.

5. Evaluation feed back
When a fire mission is executed, the feed back will given that the mission is over. At this point the C2 cell has to decide whether to evaluate the fire mission and its result or not. If the fire mission has to be evaluated, a detection resource must receive the order to perform a damage assessment on the target.

In the picture there is a decision "next action" this will not be modelled as a C2 process but will be a decision process of the fire unit, which consumes no time.

4.4 Measures of effectiveness and measures of efficiency

In the code of best practice developed by NATO AC/243 (Panel 7) TR/8 RSG-19 on Modelling of Command & Control, Chapter 3 describes several types of measures. In this document the following definitions are used:
1. MoFE, Measures of Force Effectiveness
2. MoE, Measures of Effectiveness
3. MOP, Measures of Performance
4. DP, Dimensional Parameters

We will use these definitions to describe the measures which will be used in SMARTER. Following the hierarchy of measures we will start with the MOE's and will end with the MOP's. Because SMARTER is a model developed for the evaluation of the performance of field artillery we think it is not possible to define MoFE's.

4.4.1 MOE

The mission of a force usually will not be defined in measurable units. Therefore a translation of the mission for both the force and the artillery is necessary. In SMART the original mission was

to have such an influence on the enemy that the willing to continue the conflict was gone. This mission was translated into a goal where the total strength of the enemy forces at the end of the mission must be lower then a specific value. Strength then was defined as the percentage of the original capabilities of the individual units. When the strength is less or equal to the goal the mission was a success otherwise the mission failed. The strength of the enemy forces can be written in a formula in the following way:

$$\frac{\#\ \text{Targets Destroyed}}{\#\text{Targets offerd}} \quad \text{or} \quad \frac{\sum_i \text{Strength Target}_i}{\sum_i \text{Initial Strength Target}_i}$$

Usually we will use the second description for measuring the strength. As mentioned in the RSG-19 paper the values of MOE will depend on the used scenario. In general this measure will be used to evaluate the performance of the simulated field artillery system as a whole. To be able to measure the used systems in a scenario a number of MOP's will be defined.

4.4.2 MOP's

The MOP's will be defined based on the basic components modelled in SMARTER. Each Component will have its own measures to be able to judge the performance of these elements.

The performance of the detection resources will be based on the number of detections and the number of correctly detected targets. In formula:

$$\frac{\#\text{targets detected}}{\#\ \text{targets offered}} * \frac{\#\ \text{targets detected correctly}}{\#\ \text{targets detected}}$$

We also want to measure the performance of the C2 and communication structure. This performance will be based on the capability to process a target detection in time and transform this message in a Fire Mission. However the C2 and communication resources have their own influence on the process we will use the following measure for evaluating the C2 and communication structure:

$$\frac{\#\ \text{Possible Fire Missions}}{\#\ \text{Targets detected}}$$

In the model targets will become obsolete after a certain time. Because targets can move, the information of targets is time dependent. Therefore a fire mission is only possible when the decision can be made in time. (When the instruction for a fire mission is given, the fire mission still can be cancelled by the fire unit.)

The measurement of the fire units is more complex. Based on the information a fire unit receives from C2 components, the fire units will be able to perform tasks. On the other hand based on the performance of the fire units (mainly based on the time needed for a fire unit to perform a fire mission) the C2 components will be able to send information to the fire units. (When the occupancy of the fire units is relatively high the C2 components will not be able to send fire missions to the fire units.)

The effectiveness of the fire units can be measured with the following number:

$$\frac{\text{\# Fire missions with effect}}{\text{\# Fire missions}}$$

A fire mission with effect is a fire mission that has effect on the aimed target.

The described measures defined above are the most essential measures defined. In the model more measures will be defined to be able to tune and optimise the system.

5. CONCLUSIONS

In this paper the concepts of the tool SMARTER are discussed. SMARTER will be used to support the Dutch army in several policy studies concerning the field artillery system. It will facilitate the implementation of field artillery simulation models in a fast and efficient way.

One of the main goals in the implementation of the tool was to develop a system in which there is enough flexibility in the C2 elements to be able to research both different levels of C2 and different C2 rules.

Communication is modelled as a resource and can be varied in several scenarios. When necessary an interface with more sophisticated models concerning the simulation of communication will be implemented.

In SMARTER it will be possible to model both own troops as enemy troops. This makes research of attrition to own troops and the survivability more reliable. Moreover when both parties have the same technology and doctrine both attack and defence can be analysed in one scenario and simulation run.

EVALUATING EFFECT OF C2 ON BATTLE OUTCOME BY TRACKING INFORMATION QUALITY

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ABSTRACT

During the period 1994-97 FFI performed a large scale cost effect analysis of alternative C2-systems for the Norwegian Army division. Included in this was a study of the effect on expected battle outcome of the main C2 capabilities. The methodology that was used, is currently being refined and further developed, and will be used in future C2 analyses at the institute. The part of this methodology explicitly addressing the relation between C2 efficiency and battle outcome is outlined in the first part of the paper. The methodology consists in mapping alternative courses of a scenario, and then calculating the C2-systems ability to control the development onto a course giving a preferred endstate. In the second part an applied example taken from the past analysis is explained.

METHODOLOGY

This section briefly describes a methodology for effectiveness analyses that incorporate both weapon systems effectiveness and C2 effectiveness into a measure in terms of battle outcome.

Integrating structure analyses and C2-analyses

A C2-analysis needs as a starting point an extensive description of both the system to be commanded and controlled, and the environment the system operates in. It relies on assumptions about the kind of operations the forces are supposed to perform, and scenarios describing operations and factors relevant for battle outcome must be made, like in traditional force-structure analyses.

In addition to a description of the intended course of the operation, the other possible courses of development of the scenario must be mapped, especially taking into account alternative actions for the two sides in the battle. This scenario-building process will result in at tree where the nodes are situations, and the branches are plausible scenarios, each with a final outcome (leaf-node). The build up of a scenario-tree is comprehensive, but as it will be shown in this paper, each scenario can be explained by a very coarse description. The aim of the C2-study is to calculate the extent to which the C2-organisation is able to "steer" among the different branches of the scenario-tree in order to reach a favourable result.

The above introduction suggests the following algorithm for an integrated structure- and C2 effectiveness analysis:

1. Develop operational concepts
2. Develop a scenario describing successful application of the operational concept
3. Identify important branching nodes in the scenario and develop scenariotree

4. Calculate endstates (leafnodes) for each branch of the scenariotree
5. Identify critical conditions for success.
6. Calculate C2-organisations ability to manoeuvre among the brances of the scenariotree, (actually analyse the C2-system)
7. Calculate expected outcome

The example in the last part of the paper will illustrate the elements of the methodology. Although this is called an algorithm, the steps are not meant to be straightforward, e. g. most readers will know the amount of work and pain behind analysing a C2-system or developing an operational concept. The next point describes some of the main characteristics of the C2-analysis methodology.

C2-study methodology

It is easily seen that if the end-states can be evaluated in terms of whether the war is won or not, or in terms of probability of reaching political goals, application of utility theory is straightforward, and the expected outcome will be an indisputable measure of merit. This is more generally true if the axioms of utility theory applies to the goals of the armed forces, and in the following, this is assumed to be the case. In the described methodology, a C2-analysis is divided into four subanalyses, answering four basic questions:

1. What is the quality of the information the organisation is gathering about its environment?
2. With what quality is it *possible* to predict the development of a situation over the time interval from a situation occurs till it is detected and decisions based on this situation have an effect on the battlefield?
3. What is the quality of the organisations reasoning (including prediction and decisionmaking)?
4. With what quality are decisions carried out?

The four questions correspond to the fact that an organisation with certain objectives in the real world has to sense this world, reflect and reason over own possible actions and expected outcome, and then carry out the seemingly best action. If the objectives are not reached in an optimal way, it is either because the world has changed in an unforeseen way before the decision is having effect, or due to imperfections in the way the three mentioned tasks are performed. As a total, the four subanalyses will answer the question about the C2-organisation's ability to steer own actions and the development of the environment into a favourable endstate. The analysis that is described in this paper is only part 2 of the total analysis.

Quality is measured by the same three parameters in each subanalysis. (The terms are denoting information quality, but the concepts apply to carrying out as well):
1. *Correctness* - probability that main content of information is correct
2. *Precision* - inverse of standard deviation, given that main content is correct
3. *Completeness* - second order parameter, denoting the portion of subinformations in a large picture that are not significantly less precise than the rest.

A study of various information quality criteria concluded that information quality is only well defined relatively to a definite decision. Correctness is then the probability that the alternative action that is best according to the information, handles the actual situation. Precision is similarly defined relative to the degree of detail of the decision, and in measuring completeness, the subinformations are weighted by their importance or value in the decision.

The results of each subanalysis is easily integrated, basically using inference rules of probability theory. As information quality is tracked all the way from the organisations sensing of its environment, through predictions, decisions and actions on the organisations environment, the effect of each component of the C2-organisation is thoroughly linked to battle outcome.

Iterations of effectiveness analysis and modifications

An C2-effectivenss analysis will usually (but not always) be part of an iterative process of development and improvement of planned systems (evolutionary approach). If the above algorithm-description is taken literally, it results in a single point measurement of effectiveness in the space of possible C2-concepts. On the one hand it will be seen that it is possible to achieve more general results, e. g. in the reported analysis force effectiveness as a function of reaction time is calculated for all values of the given reaction time, although not taking into account a shift in optimal concept of operation. On the other hand, if all three information quality criteria are tracked all the way through the decision process, the results suggests a direction to go for a more optimal solution. As is discussed in (Sundfør 1996) low precision mainly suggests reconstruction of the decision itself, e. g. coarser early decisions, and postponed details. Low completeness suggests reconstruction of the decisionmaking process with fewer, more aligned subprocesses. Correctness is of course the main measure of effectiveness for the C2-system, as it is most directly linked to battle outcome. A correctness that remains unacceptably low despite optimisation effort, simply suggests that one is unable to support the operation and the operational concept in the given setting.

ARMY C2-STUDY

The effectiveness analysis that was carried out during the Army C2 study at FFI focused on tempo and time-consumption in intelligence- and decision-making processes, and resulted in a recommended C2-organisation on division level. Time-consumption in various decision-making processes was calculated by simulation of planning procedures and communication, taking physical threat and need for parallel-processing as input from the scenario. The methodology used for this is reported in (Berg & Bergene 1997 and Bergene 1998). The goal of the force effectiveness analysis was then to integrate these speed parameters with the totality of force performance. This section of the paper illustrates application of the methodology based on problems that were studied during the Army analysis. Some of the actual data, scenarios and input that were used are classified, hence this paper can not report actual results.

The operational concept and ambitions for the division (here denoted "grey division") was given prior to the study. In one of the studied scenarios, the ambition of the grey

division is to destroy an advancing white force, retaining a certain amount of own force, necessary for a later mission. The mission accomplishment criteria was then well defined, and achievement of the ambition was in turn linked to national security by higher level scenarios and analyses.

Grey concept of operations in this scenario is to initially control white advancement while keeping main own forces remote, and then successively stop white forces in front, attack the force in a cut-off operation, attack it again in a dividing operation and finally destroy the two encircled parts. Favourable outcome should be gained by concentration of grey firepower and forces which gives a locally high force ratio wherever grey is engaging in decisive battle.

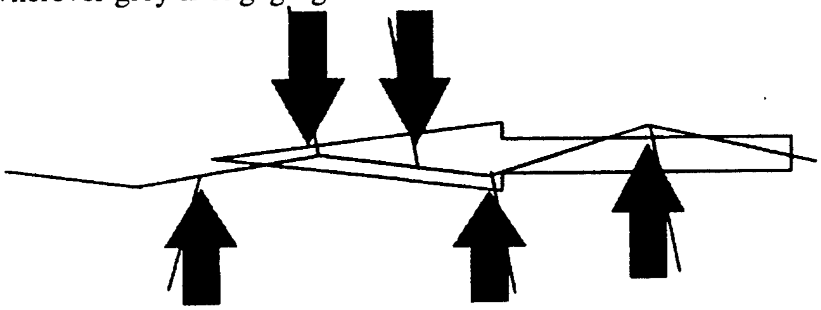

Fig 1 ***The figure illustrates how grey forces can attack the advancing white force along one out of several different axes.***

More detailed scenarios instantiating the concept was developed, and the example that will be used here is illustrated in figure 1. One main axis is leading through the battlefield, along which white forces are advancing, whereas five sideaxes lead onto the main axis between the stop- and cut-off areas. One important branching node in the scenario is given by the five grey options for the dividing operation, and a continuum of white options in deploying their forces. Other branching points, such as the various options in choosing a region for the total operation, and the options for stop- and cut-off operation were also studied. Further, within these main courses of action, grey side will also have a larger, continuum-like set of options. One example of this will be described later, namely the precise location and timing of the grey attack on the main axis corresponding to location of mobile white units on that axis.

A comprehensive scenario description and battle outcome calculation revealed important symmetries among the axes. The division is likely to reach it's ambitious goal if and only if the brigades carrying out the cut off and divide operations do not meet organised resistance from a white force greater than a certain threshold[1]. If grey brigades are met by sufficient white forces on the narrow axes, the operation is likely to stop, and turn into attrition duels with about equal losses on both sides. In the overall setting, such attrition combat leads to highly undesirable results. For readability, the minor variations among the five options are omitted in this presentation, and the endstates of all the main branches are then either likely success or likely failure. Variation in endstate due to variations in deployment during the attack were also calculated by simulation. Deployment affects the order in which grey engage various white units, which in turn influences battle outcome.

[1] Details can be found in (Taugbøl & Moen 1996).

As is seen, the above description briefly goes through step 1 to 5 of the suggested algorithm. In step 6, the C2-analysis, focus was put on speed in decision and operations, and on the extent to which it was possible to predict the situation over the time intervals from sensing to the effect of the decision. Predictability of the battlefield was calculated by two different approaches, reflecting two different aspects of warfare:

- Game aspect: Predictions are difficult since enemy plans are unknown. Each side is aware of own alternative actions and enemy alternatives, and acts to maximise the probability that the enemy will be unable to handle own actions. A negative outcome is considered a result of calculated risks and of foreseen possibilities.
- Opportunistic aspect: Predictability is distorted by a variety of lower level factors affecting the dynamics of the operations, factors which can not in practice be overlooked or planned for. Each side is acting to exploit upcoming opportunities, and the two sides' decisions are modelled as temporarily independent.

GAME ASPECT

The game aspect reflects the total symmetry in many warfighting situations. If one side intends to outmanoeuvre his enemy, the other side is certain to have the same intentions. Moreover, in his attempts on outmanoeuvring, the enemy might consider what his adversary is most likely to do, again based on assumptions of what he will be expected to do. Unpredictability of the situation is then a consequence of each sides effort to be unpredictable as a means to maximise chance of a favourable outcome. Still, as limits to predictability is symmetric, the same symmetry is also a limit to unpredictability, as it limits both sides ability to choose the unforeseen and unhandled alternative. The symmetry of the decision problem is reflected in the model as a mutual consistency requirement between assumptions about the environment and optimal own actions (a game theoretic model).

The situation is interpreted mathematically as a two-player, zero-sum game. Depending on the speed and flexibility of each sides decision-making process, the players will have to make commitments for future actions at various times, or more precisely, based on knowledge of the situation at various times. A commitment of resources (e. g. forces, reconnaissance, planning capacity) that limits future options is called a move, and can either be taken on or before the branching point of the scenario-tree. If a grey commitment is visible to white before white is making some other commitment, grey is said to make a move *truly before* white makes the other move, and visa versa. When neither of two moves is taken before the other, they are said to be simultaneous or quasi-simultaneous. Various combinations of C2-capabilities on both sides will give rise to distinct orders in which the moves are made, and thereby different games. Since the games are zero-sum, there exists a Nash-equilibrium in mixed strategies, and a unique value for the game, that can be found by linear programming[2]. In a game situation that will either fall out in favour of white or grey, this value is easily interpreted as the best feasible correctness in the

[2] The practical problems that usually occur in describing and solving complex games, is not necessarily a limitation here, as the game model for decisionmaking only applies to simple games with just a handful of distinct strategies.

prognosis that each sides decision are based on. It is important here to note that variations in grey C2-capasity is not modelled as changes in the ability to win within a game - *changes in C2-capasity changes the game and the game matrix, thereby changing the value of the game.*

In the example used here, grey has five feasible courses of action, corresponding to the five axes, where each alternative could be countered by a white force securing the axis. The problem is therefore reduced to the question of how grey division can avoid meeting such a force. Grey force can choose which axes to attack along, and white force can choose where to deploy his units. The presumably complex game matrix is then reduced to a matrix of zeroes and ones, and as the game was totally symmetric with respect to axes, the mixed strategies in the Nash equilibrium of any subgame of simultaneous moves will consist of equal probabilities for each of the feasible axes.

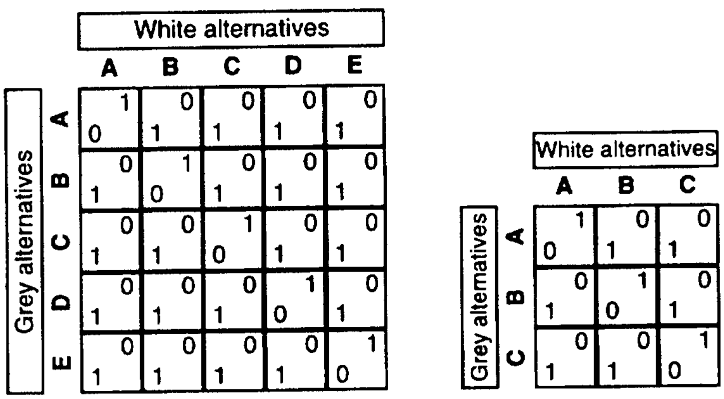

Figure 2 ***Examples of game matrixes for typical subgames that the actual games are composed of.***

The decision structure on both sides for the dividing operation can then be established. The methodology is to fix a reasonable white decisionmaking capacity (Bergene et al 1995), and then vary grey capacity. The sensitivity of the result to white capacity is then in turn analysed. In grey concept of operations grey would move brigades on outer lines, whereas white could counter the manoeuvres by moving less than a brigade on inner lines as illustrated in fig 3. Were it not for white reaction time, white could therefore choose strategy truly after grey. In fact it was seen that white force could choose his course of action truly after grey if either white had already planned for the alternative, or grey had a certain delay after the point where the actual manoeuvre was revealed[3].

If white can choose axis truly after grey, grey will never succeed. On the other hand, without a grey delay in the final phase, white can only catch up with the situation if he has planned for this particular alternative. The probability of grey success then depends on the number of alternatives white has planned for, and the rate by which white can become aware of and prepared for the five different alternatives is calculated from white C2 capacity. The order by which the alternatives were considered, is here assumed to be random. This gives the same result as the game-

[3] The delayed alternative is particularly interesting as this might be a consequence of an extended need for planning and coordination on brigade level.

theoretic solution, which recommends random-like behaviour. Depending on the time of the grey attack, this yields a probability for grey success. If the attack is countered by a white manoeuvre, grey might try another axis, and the probability of success in this case is similarly obtained. However, white is fairly soon able to handle all the various alternatives, and probability of success in the second or third try is limited.

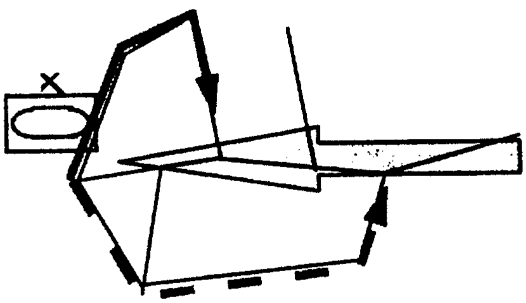

Figure 3: ***The figure illustrates how grey change of axis implies manoeuvring along outer lines.***

White need to keep a sufficient number of units moving forward and pressuring in front at each time, limits white's ability to cover axes with the necessary force, and the actual capacity was found in scenario-studies. The same limitations were seen to be there as white force is stopped in front and becomes temporarily static. Predicting white deployment after the stop operation was seen to give little more than the assumption of randomness. As before, the optimal strategy for white is to behave random-like, which gives the same result, and it is then unimportant whether white makes a random or conscious decision on this particular point. Whether grey decision is taken before or after the time when white becomes static, is then the second important parameter in setting up the game, along with the planning rate.

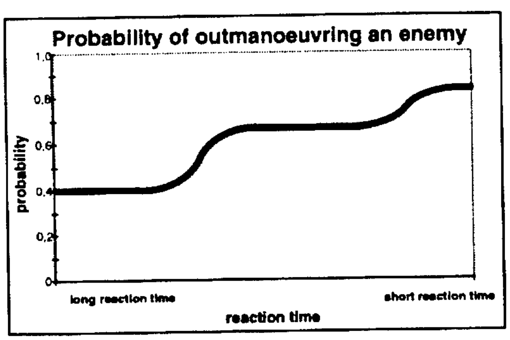

Figure 4 ***the figure shows calculated probability that grey will outmanoeuvre white in one dividing operation in the studied scenario.***

Supposing that grey could carry out the dividing operation without delays in the final phase, the probability of grey success when gambling on one axis at the time depended only on total grey reaction time for this particular operation. Grey could not launch the attack till a certain time (called "g-time") after the stop operation[4], and with a reaction time shorter than this time, he can choose course of action truly after

[4] Such limits to speed will occur both due to phasing of the total operation, and due to the time it takes to transfer the brigade to the attack area

white has "decided" which axes to initially cover. If white happens to be prepared for this alternative, grey could make another try, with a resulting delay and increased white preparedness according to white planning capacity[5]. For longer reaction times, the optimal solution for grey is to make an initial choice before the stop operation, and then change the plan afterwards in case the planned axis is covered by white. The risk that white counters the plan is then increased due to the delay. If white is prepared to counter the attack, the option to make another try is still there. The calculations resulted in probability of success as a function of reaction time, which is illustrated in fig 4.

OPPORTUNISTIC ASPECT

Not all decision-problems in a war are symmetric, and the reason for this is human limitations in handling complex and dynamic problems. It is reasonable to assume that both struggling sides could be aware of the various courses of action that were treated above, but it is not feasible to assume that all the thousands of minor variations within each course of action is treated similarly. Rather, these minor variations are a result of many people's rather independent decisions, and for a distinct decisionmaker, they are treated as random variations. Further, as one of these variations suddenly seems to give more opportunities than the rest, there is no reason to believe that the enemy should be aware of this, that he has considered it, nor that it is all part of a grand plan. In other words - these opportunities suddenly occur and disappear due to random variations, they occur independently of our ability to exploit them, and they have to be caught within a short window of opportunity. The opportunistic aspect reflects these asymmetric, one sided decision problems. The asymmetry is modelled as a one way dependency from the probability distribution over various future developments to the optimal decision, as opposed to the mutual dependency of game theory.

When there is a continuum of possible future states, unpredictability has to be described as a parameterisation of the actual probability distribution. A standard deviation for the probability distribution of the future position of a moving unit was calculated (Sundfør 1997)[6]. The calculations were based on mathematical models of how various classes of phenomena contribute to the uncertainty as a function of time. Quantitative estimates on occurrence of these phenomena were then made, based on the experience of skilled officers. The best possible precision in a prognosis was then given as a function of prognosis horizon, or equivalently - of reaction time.

Typical opportunities that one would like to exploit were identified in the scenario through wargaming and scenario-discussions. The identified opportunities consisted in gaps in enemy deployment, and the size of these typical gaps was measured. The probability of hitting the gaps could now be calculated, still as a function of prognosis horizon.

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[5] Too many successive tries would result in a delay that threatens the overall operation, if the operation is threatened before white force is totally aware of the situation and can counter any attack, it will be a limitation that should be considered.

[6] The considered distribution is actually the conditional distribution, given that main enemy intention is correctly predicted.

Uncertainty in future enemy deployment

The mathematical model divided all information-distorting phenomena into three classes:

- Uniformly distributed and mutually independent delays or absence of expected delays. With a few minor simplifications, this yields a standard deviation of the form: $\sigma(t) = T\Delta v\sqrt{\rho t}\sqrt{\sqrt[3]{{(t/T)^3}/{2} + 1} - 1}$, where t is time, T is the typical delay, ρ denotes density of delays (in time), and Δv is the speed difference. Computations are slightly more complicated when independently moving subunits and queuing effects are taken into account.
- Regular changes in speed with known average period and speed difference but unknown phase. This is mainly each units alternation between advancement and consolidation / rest / reorganising. For simplicity, equal expected duration of both movement and rest at each level was assumed. The component of the standard deviation caused by each level is then given by $\sigma(t) = t\Delta v\sqrt{t/3T - t^2/4T^2}$ for $t < T$, and $\sigma(t) = T\Delta v\sqrt{1/12}$ for $t > T$ where T is the typical rest- or advancement time and $2T$ is the typical operational period of a unit. Uncertainty regarding several organisational levels are fused by adding variances.
- Uncertainty in factors affecting the mean speed of advance. This includes uncertainty in equipment performance, enemy intentions and enduring effects from own fire. For limited time intervals this gives a linearly increasing standard deviation, given by $\sigma(t) = \sigma_v t$, where σ_v is standard deviation of mean advancement speed. Cohesion in higher units will though make the deviation concave as a function of time. The uncertainty is typically a fraction of a unit's speed of advance, and the deviation will increase with this rate for as long as the unit can operate independently of higher units. For excessive time, it will increase with a fraction of the mother unit's typical speed, and so on.

The various phenomena leading to uncertainty were described, and quantitative estimates were made through the experience of skilled officers (Sundfør 1997). Field experiments were not performed. The total variance was taken as the sum of the variance components ($\sigma^2(t) = \sum \sigma_i^2(t)$), and due to the large number of contributing effects, it was assumed that the final distribution is a normal-distribution, although each component is not. With this simplifying assumption, the standard deviation totally describes the uncertainty.

The normal distribution assumption was only assumed to be valid for the conditional distribution, given that main course of action is correctly guessed. When several distinct courses of action are feasible, a normal distribution is of course highly unlikely. Moreover, the mathematical model did not distinguish between dimensions (although such extensions are possible) so it should actually be interpreted as describing one-dimensional movement along an axis. One-dimensional uncertainty in a continuum is not in general consistent with uncertainty in course of action, but is reasonable for the conditional distribution.

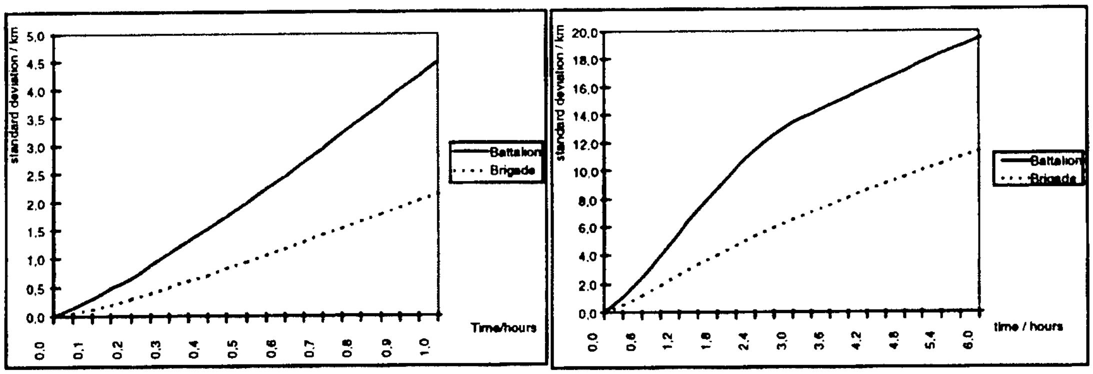

Figure 5: ***The calculated uncertainty for enemy unit position as a function of prognosis horizon. The uncertainty is seen to increase convexly for small times, and then concavely for larger times.***

In the calculations, a battalion was seen as a compactly moving unit, and therefore the level experiencing delays, orientation problems and so forth. A brigade was then modelled as a cluster of battalions. Occurrence of some of the uncertainty-generating phenomena are typically positively linked throughout a brigade, some are independent and some might be negatively linked. These correlations were taken into account as the variance of brigade positions was calculated. In addition, the most important queuing phenomena were taken into account, namely that depending on the nature and duration of a delay, one or more following battalions either has to queue up behind a stopped battalion, or they are delayed as they pass by it. The calculations resulted in quantitative estimates of the uncertainty in the position of a dynamically advancing battalion and brigade as a function of prognosis horizon. Figure 5 illustrates the results.

Operational consequences of speed in opportunistic decisions

An important feature in manoeuvre warfare is the ability to exploit upcoming gaps or weak points in enemy deployment, while avoiding the hard points or surfaces. The effect of engaging logistics, artillery and tank units in that order relatively to the opposite order can be calculated in traditional combat simulation models (Taugbøl 1995). Through operational scenario-considerations the gaps in deployment that are likely to occur and to be exploited by own forces can be identified[7].

When exploiting a gap, the gap has to be seen after it has occurred or foreseen as it is coming into being. The size of the actual gap is defined by the position of the hard units or surfaces on each side, and uncertainty in existence and size of the gap is then decided by the size of the expected gap, together with uncertainty in position of the units defining the limits of the gap.

In the scenario-example exploitation of upcoming opportunities occurred a few times. In one case own forces should secure and use a passage through enemy positions in order to take up favourable positions for the further battle. In the other case artillery units were to be attacked and destroyed in the gap between two battle units. Other

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[7] Similar calculations as those referred to in the previous section might be combined with scenarios to estimate absolute and relative frequencies in the occurrence of various gaps in deployment. This has not been done in the reported study, but is a natural extension of the theory.

situations were also seen. Based on a scenario, the size of the gap is easily established. White operation modus in these situations is also identified, and will affect the rate at which prediction-distorting phenomena occur.

The best possible quality of a prediction about position and nature of such a gap can now be calculated. If available intelligence and understanding of enemy operation is fused in an optimal way to produce a prediction of such a gap, and the plan is to hit the centre of the gap with an own attack, the best possible correctness of a prediction is the probability that this attack actually occurs between the considered units. The probability for this was taken as the probability that neither the left unit is more than half the gap size to the right of predicted position, nor the right unit is half the gap size to the left of predicted position. A typical result is shown in fig 6.

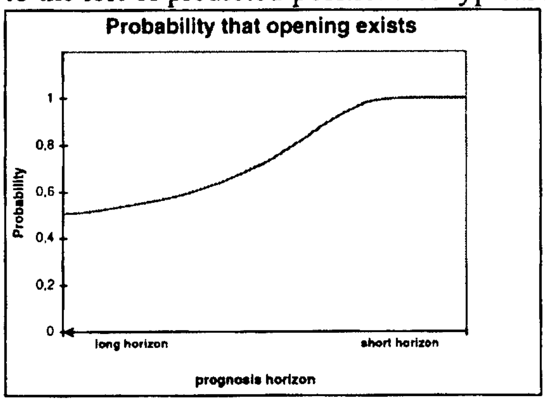

Figure 6 ***When one is foreseeing an opening between two enemy units, the probability that the expected centre of the opening will actually be within that opening, is given as a function of the prognosis horizon.***

It is seen from the figure that the probability of success falls steeply when prognosis horizon exceeds a certain time. This time also includes transportation to the attack area. When a total reaction time is calculated for this operation, the effect of limited changes in the time spent in decision-making process and in the intelligence fusion process can be read directly from the graph.

The standard deviation is indicating precision, but is here transformed to a correctness indication. The described situation also illustrates the iterative step, where a mismatch in precision suggests a change in the sort of gaps it is sought for in the decision. To handle such a mismatch, the operational concept can be modified, or the decision can be restructured into preliminary and final steps.

CONCLUSIONS

The paper has described a methodology for an integrated C2- and force effectiveness study. The methodology has been successfully applied in a recent project at FFI with emphasis on the relationship between speed in a C2-process and battle outcome.

The methodology consists in partly separate modelling of battle-scenarios and battle outcome on the one hand and C2-systems and capabilities on the other hand. The analysis is then integrating the parts, calculating various branches of the battle scenario, calculating C2 capabilities in the setting of the scenario, and then in turn

calculating the C2-systems ability to steer among the branches, thereby achieving the preferred endstate.

Examples related to a recent Army C2-study is then used as illustrations of the methodology. For a particular divisional mission, the relationship between speed in decision-making process and battle outcome is calculated. The problem is decomposed in two aspects, yielding different models of the decision-problem. The game aspect is assumed to be relevant for the main decisions of each level, where a limited number of feasible alternatives are known and possibly considered by both sides. The mutual consistency requirements of game theory, between optimal own actions and the probability distribution over future developments then apply. The opportunistic aspect applies to the details of a decision, where there are huge numbers of alternatives, and the time for considerations is limited or absent. In this case, there is only a one-way dependency from the probability for various future developments to the optimal own action. Unpredictability of the scenario is calculated, taking both these aspects into account, and the relationship between speed and battle outcome is established.

Although the analysis example takes into account only one part of the C2-process, the entire framework for integration of traditional force effectiveness analyses and C2-analyses is established. Quantitative result from analyses of other measures of effectiveness, (such as quality of reasoning or carrying out) can then easily be integrated. The effects of these various characteristics about the C2-organisation will then be comparable. When force structure is varied in the battle outcome calculations, C2-capacities are also directly comparable to weapon systems when it comes to contributions to the overall outcome.

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Analysis of Combat System Demands on a C^3IS Architecture

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1. Introduction

A military Command, Control, Communications and Intelligence System (C^3IS) provides a Commander with the means of directing and co-ordinating the operation of his combat resources to achieve his tactical objectives within his operational environment; this requires that the facilities provided by the C^3IS match the scope of the tactical objectives, the vagaries of the operational environment and the demands of the various combat resources. In general, C^3IS development has followed an evolutionary path in response to the progressive improvement of individual combat systems; however, there are a few occasions when the introduction into service of a new combat system has led to the need to examine the implications for the C^3IS. The majority of these have been when the combat system offered a major improvement to the war fighting capability of the force; the arrival during the next few years of the Attack Helicopter (AH) into the British Army's inventory is perceived to be just such an occasion.

The modern Attack Helicopter with its onboard mission planning systems and its data transfer communication capabilities is expected to have a major influence on future C^3IS requirements of ground forces. The introduction of the Attack Helicopter with its range of new and extended capabilities will enhance the British Army's effectiveness and range of options in a variety of scenarios; however, the control and management of these new capabilities are expected to place new demands on the C^3IS which may require modification or extension of the existing C^3IS architecture. This paper describes an integrated modelling approach that was developed to support investigation of the C^3IS and AH Mission Management System capabilities that will be needed to maximise the effectiveness of battlefield aviation; it discusses the application of the approach, showing how it was used to meet the study requirements.

1. Background

The objective of the study was to identify when and how a C^3IS could intervene to support an AH mission, and to assess the influence of these interventions on mission effectiveness; in consequence, the study focused on the structure of AH missions and on the timeliness and relevance of these interventions within the context of an AH mission. The starting point for this study was a set of AH task analyses derived from a series of interviews with military subject matter experts.

The purpose of these interviews was to use military experience to derive the sequence of events within a mission and to determine the information which would be available to the

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The study described in this paper was carried out under MOD Contract CDA/E/295.

mission commander (MC) and the AH commanders to aid them in conducting the various mission tasks. This data was recorded in a database as a series of events and the associated information that would be available to the commanders at each event; in addition, the related information sources and sinks were identified and recorded in the database.

Initial examination of the task analyses [MOD, 1996A] showed that AH missions could be represented as sequences of phases and associated events, each with its own physical and information requirements; it was apparent that the mission effectiveness would depend on the outcomes of these events and that these outcomes would be influenced by interactions between the AHs and the C^3IS. This examination showed that AH missions and the associated interactions between the AHs and the C^3IS could be simply and intelligibly represented by state-event graphs using the Petri net approach [Peterson, 1977].

A Petri net state-event graph of a generic AH mission was developed to investigate this approach to the problem, and to identify any deficiencies or shortcomings in the data captured during the interviews. This analysis highlighted two aspects of the representation that required further attention, namely:

- the physical interactions between the AH team and threat systems and the consequent generation of mission effectiveness data;
- the influence of the MC's decisions on the outcome of subsequent events.

The forms and outcomes of many of the events within a mission are highly dependent on spatial relationships that do not lend themselves to inclusion in state-event graphs [MOD, 1996B]. Consideration of this problem led to the decision to use specialised, detailed, vignette models to examine critical, spatially dependent, events and to integrate these vignette models into Petri net models of the overall missions. These vignette models are detailed, specialised, combat models that take account of spatial factors, such as terrain masking; the models are primed with data defining their initial states to allow estimation of the effects of previous events, including C^3IS interventions, on their outcomes and thus on mission effectiveness [MOD, 1994].

A second set of interviews with military subject matter experts was undertaken to identify the factors that would influence MC decision making. These interviews led to the conclusion that the most important result of C^3IS intervention would be on the quality of information available to the MC and that this information quality should be expressed in terms of the following parameters:

1. *existence*: whether a data item is available for mission planning and control;
2. *accuracy*: the degradation of a data item due to errors of observation, transmission and interpretation;
3. *timeliness*: the time of availability of a data item;
4. *latency*: the age of a data item at its time of use;
5. *confidence*: the perceived reliability of a data item.

These interviews also indicated that information quality would affect mission effectiveness by determining whether a particular activity would be carried out, and by influencing the results of the vignette; for example, by influencing the MC's decision to conduct reconnaissance to increase his knowledge of the threat, and then affecting the outcomes of the reconnaissance and of any subsequent task. This showed that the AH Mission Model would have to represent both real and perceived information qualities, and that it would have to model the MC's decision process at critical decision points.

A single mission type and scenario were chosen to provide the basis for further development of the modelling approach, and a detailed task analysis study of the selected mission type was conducted to refine the definition of the mission tasks and their information requirements. This task analysis encompassed command levels from the HQ tasking authority through Aviation and Mission Command to the individual AH; the information requirements determined from this task analysis were further developed to determine the information exchange requirements for the mission scenario.

1. Development of the AH Mission Model

3.1 Overview

The task analyses and the related information quality metrics provided the foundations for the development of the AH Mission Model which was used to evaluate the C^3IS support requirements for AH missions. The criteria used to select the modelling approach were:

1. The model must have a verifiable derivation from the task analyses.

2. The model must employ the information quality metrics in such a way as to represent the dependence of perceived and actual information quality on elapsed time and on the origin of the information.

3. The model must represent the dependence of the mission's evolution and outcome on both the perceived and the actual information quality.

The task analysis data lent itself to representation as a coloured Petri state-event graph, in which MC decision making was represented using Bayesian inference networks. The outcomes of the various combat events occurring in an AH mission were analysed using detailed vignette models and the results fed back into the Petri net model.

3.1 Network Development

The timed, coloured, Petri net method [ISO/IEC, 1997] allowed AH missions to be modelled in terms of sequences of AH and C^3IS activities. The structure of the network was derived from the mission task analysis; individual activities and tasks were grouped in terms of their interactions and dependencies to form a hierarchical network representing the different AH and C^3IS activities in the successive mission phases.

This state-event representation simplified the tasks of tracking the flow of information between the various activities and of monitoring the sources and ageing of this information. Inclusion of the accuracy and timeliness factors required the use of special facilities provided by the EDS Petri Net Tool [EDS, 1998], in particular, the ability to code complex behaviours into the network nodes, and the facilities for accessing external data sources.

Figure 1 shows one sub-network in the hierarchy of networks that make up the AH Mission Model; the rectangular nodes in this sub-network designate *transitions* which represent individual activities or events, while the circles denote *places* identifying the states resulting from these events; the shaded nodes contain further sub-networks related to lower level tasks and activities. Each transition in this network represents the sequence of activities associated with a particular mission phase (e.g., "Mission Prep"), while places, such as "at FRV" ("at Forward Rendezvous"), identify the states achieved at the end of these phases; the double boxes (e.g., "Log-in accepted") mark connections to other sub-networks representing the activities of the C^3IS and other external elements.

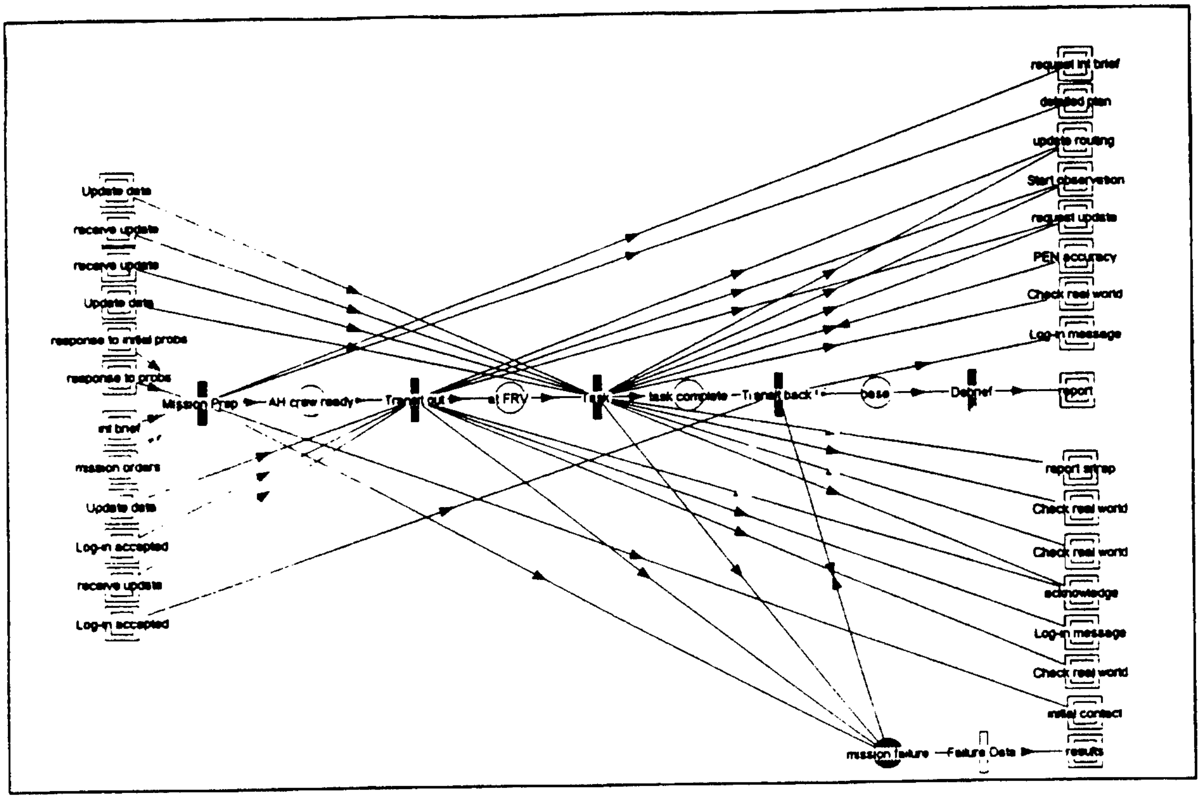

Figure 1 - State-event graph of an AH mission

3.1 Information Quality

The first four information metrics (existence, accuracy, timeliness and latency) reflect the behaviour of the AH Mission Management system and the battlefield C^3IS; the Petri net model handles these metrics by assigning the following parameters to the tokens associated with individual data items:

a) time stamps identifying when they were created,

b) intrinsic error bounds related to the standard deviation, σ, of the error distribution on the data items due to inaccuracies in observation, processing, etc., and

c) a rate of increase of the error bounds representing the increase in uncertainty resulting from the evolution of the situation.

Parameters b) and c) are intimately related to the characteristics of the battlefield systems originating and transferring the data, to the current scenario, and to the environment within which the scenario is located; consequently, these dependencies must be reflected in the values assigned to the attributes. In the absence of detailed evidence, the simplifying assumption was made that the related error bounds would increase linearly with time, as shown in Figure 2.

The Time axis in this figure represents the normalised value of the data item, while the line A-B represents its true value. The Error Tolerance embodies expert judgements of the margin of accuracy required to carry out a particular task, and corresponds to an 80% confidence that the actual value of the data item lies within these margins.

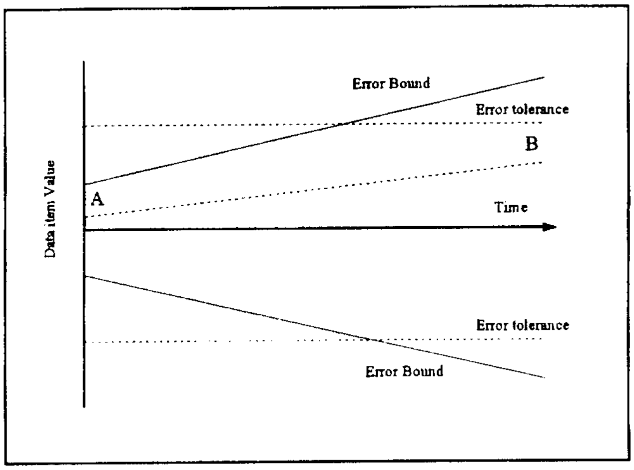

Figure 2 - Variation of Data Accuracy with Time

Additional assumptions were that the measurement and estimation errors would be normally distributed, and that the MC would have an accurate appreciation of the observational errors and their rates of increase for different data sources and data types. These simplifications are justifiable on the grounds that the AH Mission Model is aimed at assessing the overall influence of the C^3IS on general mission effectiveness rather than at exploring the fine detail of individual missions.

3.1 Mission Decision Making

As discussed above, the confidence metric represents the way in which the belief that a data item lies within a particular range influences the selection of particular courses of action; as such, it is a function of the data item's parameters discussed above and of the importance of the individual data items in choosing between alternative courses of action; for example, lack of confidence in the accuracy of the situation report may cause the MC to decide to carry out a reconnaissance prior to an attack. This influence of belief on the selection of a course of action may be expressed in statistical form as the posterior probability, $p(f_n(x_i(t))|x_i(t))$, that the MC will select one of N possible courses of action, f_n, after a delay t due to one of I data items being assigned the value, x_i. Bayes theorem shows that the relationship between the posterior probability and the data item is

$$p(f_n(x_i(t))|x_i(t)) = \frac{p(f_n(x_i(t))).p(x_i(t)|f_n(x_i(t))}{p(x_i(t))} \tag{1}$$

where $p(x_i(t))$ is the probability that x_i has its observed value, $p(f_n(x_i(t)))$ is the prior probability of selection of f_n, and $p(x_i(t)|f_n(x_i(t)))$ is the likelihood that the data item will be found to have the value $x_i(t)$ given the choice of f_n.

In this case the prior probability and likelihood values will have been determined during the planning process and will relate to the time at which the plan is expected to be put into effect. The value of the data item $x_i(t)$ can then be related to the extremal acceptable value, $x_{i,\lim}$ for the option f_n, which is determined by the relationship

$$\text{Decide } f_n \textbf{ iff } \forall f_m : ((f_m \in F) \wedge (f_n \neq f_m)):$$

$$\frac{p(x_{i,\lim}|f_n(x_{i,\lim}))}{p(x_{i,\lim}|f_m(x_{i,\lim}))} > \frac{p(f_m(x_{i,\lim}))}{p(f_n(x_{i,\lim}))} \tag{2}$$

where f_n and f_m are members of the set of possible courses of action, F. It follows that the selection of the preferred course of action will be determined by the probability that $x_i(t)$ is inside the data item error tolerance value $x_{i,\lim}$; it is apparent that an appropriate choice of $x_{i,\lim}$ for a pair of options will make the prior probability ratio in (2) equal to one for those options. The relationship between $x_i(t)$, $x_{i,\lim}$ and t is shown in Figure 2 above.

Figure 2 illustrates the best forward estimate that can be made of the data accuracy, while the inequality in expression (2) represents the optimal decision criterion, or Error Tolerance, on this data item; as a result it is assumed that the selection of the course of action will reflect the decision maker's confidence in the data item, where the confidence is based on the error tolerance and on the estimated variation of the posterior probability as illustrated in Figure 3:

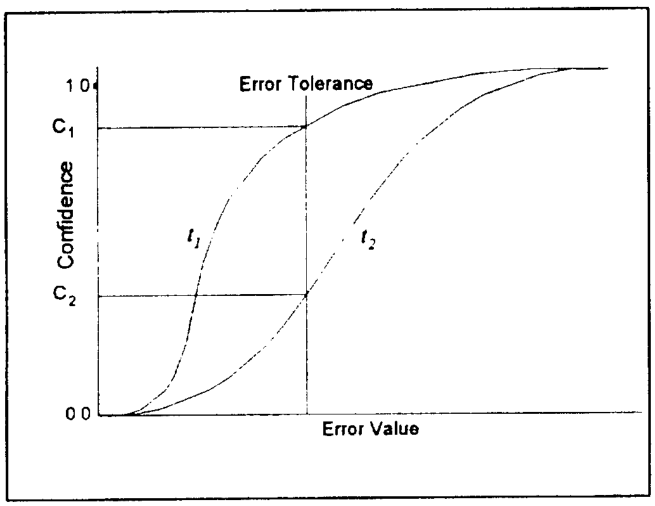

Figure 3 - Dependence of Confidence on Cumulative Error

The two curves represent the cumulative error probability on a particular data item after the elapsed times, t_1 and t_2; thus a point on either curve denotes the posterior probability that the data item has an error less than or equal to the associated error estimate. The Error Tolerance represents the maximum acceptable error, $x_{i,\lim}$ discussed above, while the Confidence, C_n, corresponds to the posterior probability, $p(f_n(x_i(t))|x_i(t))$; the figure shows how an increase in the estimated error for the selected data item reduces the confidence in the particular choice from C_1 to C_2 in the interval between t_1 and t_2. It should be noted that these elapsed times refer to the time when it is predicted that the choice will become effective and not to the time when it is being evaluated.

This approach is not restricted to selecting between two options as multiple error tolerances may be employed, each one corresponding to a different option. In this case the confidence levels for the different options are considered sequentially and the first to equal or exceed 0.5 is selected; in the event that all the confidence levels are less than 0.5 then the default option is selected.

In practice, evaluation of different courses of action is based on a composite confidence estimate derived from the confidence estimates on individual data items. Derivation of this composite estimate is complicated by the potentially large number of data items to be considered and by the fact that the error tolerances on the individual data items are not necessarily independent. The Bayesian Inference Networks approach provides a means of overcoming these problems by expanding the complex confidence estimation process into a decision tree involving simple estimation processes [Chang and Fung, 1995].

The operation of a Bayesian network is illustrated in Figure 4:

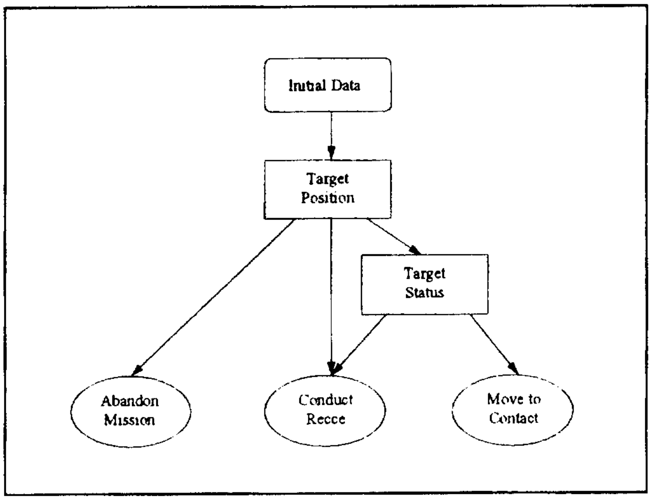

Figure 4 - Bayesian decision network

In this simple example, the decision maker's confidence in the initial data will lead to the selection of one of the three available options; this selection involves sequential application of the approach illustrated in Figure 3:

a) Consideration of the estimated accuracy of the Target Position data; this involves successive consideration of the confidence levels for the 'Target Status' and 'Conduct Recce' error tolerance criteria, and selection of the first one with a confidence level greater than or equal to 0.5; if neither criterion is satisfied then the 'Abandon Mission' option is chosen.

b) Similar consideration of the confidence level for the Target Status data to decide between the 'Conduct Recce' and 'Move to Contact' options.

In practice, a node's error tolerance may be conditioned by the responses of its antecedents. This problem can be handled by expanding the network to represent the differences in these responses; for example, 'Target Position' may have an antecedent node 'Helo Status' addressing the operational status of the helicopter group and reflecting the impact of any chance encounters; in this case the network shown in Figure 4 may be replicated two or more times to cover the different results of considering 'Helo Status'.

The expansion of a Bayesian network makes it more difficult to develop, interpret and maintain. In most cases the expanded network may be simplified by subdividing it into separate sub networks, each corresponding to a different operational context; for example, separating the cases where chance encounters have or have not occurred. This approach has the advantage of simplifying the collection and interpretation of the domain expertise needed to populate the network.

The individual Bayesian networks used in the model were coded into the relevant transitions in a recursive, data-driven form using the EDS Petri Net Tool programming language. The data used to populate the networks were collected from military judgement panels involving a range of subject matter experts.

3.1 Estimation of Mission Effectiveness

The mission effectiveness estimates are derived from results produced by a set of combat vignette models; these vignette models are run independently from the Petri net based Mission Model and produce data files containing tables of combat results, which are indexed using the perceived and actual information quality parameters. The Mission Model uses the Bayesian network results to identify appropriate tables, which are then accessed using the computed information quality parameters, thereby providing the appropriate task outcomes for use in subsequent stages of the Mission Model. This approach allows models representing different C^3IS and AH Mission Management architectures to be run using the same vignette data.

The AH Mission Model can be run either in Monte Carlo mode, to provide overall effectiveness estimates, or in interactive mode, to allow detailed examination of the factors influencing mission effectiveness.

1. Application of the AH Mission Model

The AH Mission Model uses a single Petri network which represents the structure and function of mission command, the mission and a set of generic information sources. The information sources are generic in that they represent all information sources in terms of three specific types, namely:

1. Information sources that communicate directly with the MC; these are referred to as 'comms' sources.
2. Information sources belonging to and tasked by the C^3IS that pass data to the MC via the C^3IS; these are referred to as 'non-comms' sources.
3. Information sources that do not belong to the C^3IS but which pass data to the C^3IS, where it is interpreted and the results passed on to the MC. These information sources are referred to as 'inorganic' sources.

The AH Mission Model may be configured to allow any number of updates to the MC during a mission; these updates may be requested by the MC at various points in the mission or may be passed to the MC from the C^3IS as and when information becomes available. Alternatively, the model may be configured so that no updates are passed to the MC from any update source subsequent to the planning phase, thereby providing baseline values for the measures of effectiveness. Comparison of results from these alternatives provides relative measures of effectiveness for different C^3IS configurations.

This approach requires establishment of appropriate measures of effectiveness prior to the simulation runs. The measures of effectiveness (MoEs) used in the initial runs were:

- Preparation Time
- Mission Duration
- Weapon Expenditure
- Enemy Force Attrition
- AH Attrition

The values of these measures of effectiveness were recorded for all missions and were associated with update source information to produce the model's output data. In order to establish which values of the above measures of effectiveness give the best results it was necessary to select a performance criterion which identified whether a mission was successful; the criterion used in this initial study was the destruction of 60% of the target array. Figure 5

shows how the MoE results for successful missions could be recorded, allowing the MoEs and the associated C^3IS interactions to be analysed.

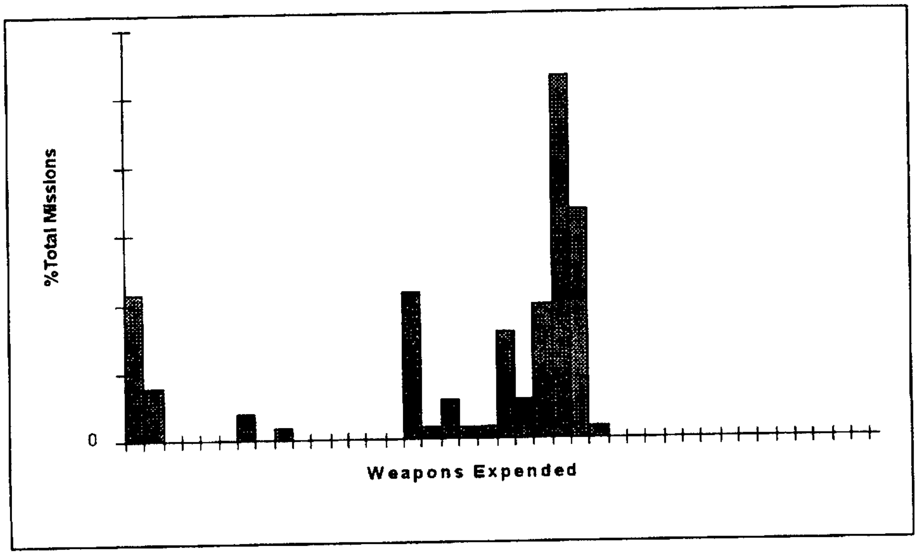

Figure 5 - Monte Carlo results

Comparison of the results from different variants of the model provided the means for comparing different the effects of different levels of C^3IS interaction on mission performance, and thereby assessing the potential influence of changes to the C^3IS and AH Mission Management system architectures.

The parameters used in the AH Mission Model were obtained from military judgement panels; much of this data was necessarily subjective, and so sensitivity analyses were used to determine the influence of variations in input data on the model's results. The initial examinations focused on the Error Tolerance values used in the Bayesian networks and used a range of Monte Carlo model runs with different measurement errors and rates of change of measurement error for the update sources.

1. Conclusions

The composite approach outlined in this paper has been shown to combine intelligibility with ease of modification and extension. It has permitted analysis of the sensitivity of mission outcomes to variations in both actual and perceived information qualities, and has provided the means of determining the way in which these variations relate to changes in the C^3IS and AH Mission Management architectures, thereby allowing identification of critical aspects of these architectures.

The use of a Petri net approach has had the advantages of helping military subject matter experts to understand and comment on the model, and of making it easier to identify and examine the dependencies within the model. The linkage with the vignette models has overcome a potential disadvantage of the Petri net approach, namely that of representing the detail of spatial interactions; in addition, the use of embedded Bayesian networks has provided the means of including military domain expertise in a traceable form.

This integration of mission management architectures, domain expertise and combat outcomes has made it possible to relate measures of mission effectiveness directly to particular mission management configurations. It has also facilitated investigation of the sensitivity of mission

outcomes to variation in perceived and actual information quality which result from changes in mission management architectures, thereby allowing attention to be concentrated on critical aspects of mission command.

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An Approach to Model Development for Effectiveness Analysis of Command and Control Systems

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Abstract

This paper describes model development as part of a cost effectiveness analysis of Command and Control Systems (C2S)[1]. The modelling method is developed by and applied in an on-going analysis at the Norwegian Defence Research Establishment (FFI), addressing development of a future C2S for the Royal Norwegian Navy. The scope of the study is the naval tactical level and the maritime part of the joint operational C2 level.

The aim of this paper is to present an approach for model development in the context of effectiveness analyses, and as an introduction to this, the framework for cost effectiveness analysis is outlined in order to relate the modelling process to the analysis. The outline gives an overview of the cost effectiveness analysis used to distinguish between a set of system alternatives.

Given this overview, we focus on model development and simulations in general and model development in connection with C2S in particular (i.e. the level between sub system analyses and operational consequences).

The general part of the model development establishes a hierarchy of desired C2S properties, Measures of Merit (MoMs), and models and experiments used to measure MoMs for each of three modelling levels established for this analysis. The three levels are the C2 sub system level, the C2S level and the operational level.

Examples of sub system level models are introduced.

C2S level modelling is the scope of this paper, and an outline of a method for developing a C2S model is described in greater detail. Aspects represented in our object oriented approach are given.

Finally, experiments employed to relate C2S effectiveness to operational consequences are described. The role of scenarios and use of war games and scenario discussions are central topics in this context.

The study is currently in its initial phases and the approach presented in this paper is still under development.

1. Introduction

The Norwegian Defence Research Establishment (FFI) has over the past years been involved in a number of projects related to C2. A main objective of one of the current projects is to recommend a cost effective C2S for the operational and tactical level of naval operations.

[1] A C2S is defined as: "An assembly of personnel, organisation, procedures, equipment and facilities organised to accomplish C2 related functions. A C2S comprises three main components: C2 tasks, C2 functions and a C2 structure." [AAP-6(U), 1995]

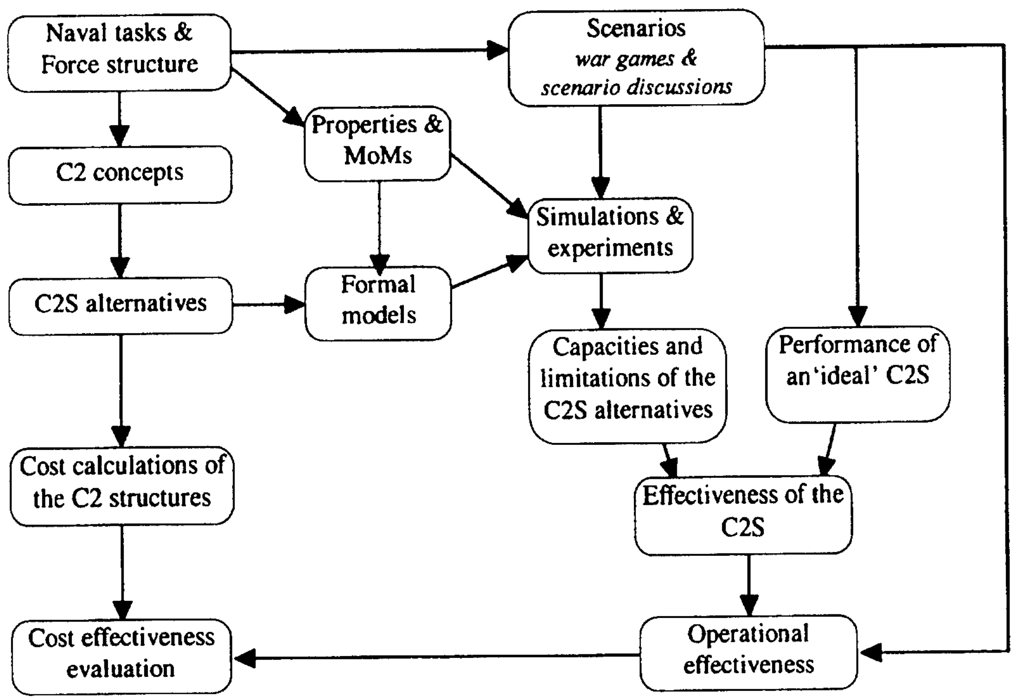

Figure 1.1 Analytical framework (scope of this paper indicated by grey box)

An overview of the analytical framework for the cost effectiveness analysis is shown in Figure 1.1, illustrating the main steps from definition of naval tasks and force structure via war games, scenario discussions, simulations and cost calculations to cost effectiveness of system alternatives.

The main steps of this framework are:

1. Development of C2 concepts and system alternatives based on naval tasks, naval concept of operation and force structure
2. Selection and definition of desired C2S properties and related Measures of Merit (MoMs)
3. Selection of scenarios covering relevant operations and further development and refinement of these scenarios through war games and scenario discussions involving senior naval officers
4. Development of formal models followed by simulation models based on C2S alternatives
5. Effectiveness analysis including studies of sub systems performance, C2S effectiveness and operational effectiveness
6. Life cycle cost calculations of C2 structures
7. Cost effectiveness evaluations

The framework of our cost effectiveness analysis is addressed in [Malerud, 1998], and is not elaborated further in this paper, except from brief descriptions of how models and experiments are related to other activities within the cost effectiveness analysis.

Given this framework, we focus on model development and simulations in general and model development for the C2S level in particular (i.e. the level between sub system analyses and operational consequences).

As part of the general description of model development, presented in chapter 2 and 3, a hierarchy of C2S properties and MoMs is established. Models and experiments used to find the values of MoMs for the C2S alternatives are also introduced.

Examples of sub system level models are introduced in chapter 4.

C2S level modelling is the scope of this paper, and a method for developing C2S level models is described in greater detail. Aspects represented in our object oriented approach are given in chapter 5.

Finally, design of experiments employed to relate C2S effectiveness to operational consequences is described in chapter 6. The role of scenarios and use of war games and scenario discussions are central topics in this context.

2. Modelling approach

Experiments and models used in an effectiveness analysis of a C2S can be separated into three levels:

1. *The C2 sub system level* - Models and experiments used to analyse single C2 sub systems such as communication networks, broadcast and ship-shore radio communications, satellite communications, sensor systems like unmanned aerial vehicles, coastal radar stations or satellite surveillance, and information systems for command and control.
2. *The C2S level* - Models and experiments used for analysis of information and decision processes in the C2S. The models also include aggregate representations of communications and sensor systems originating from sub system level analysis.
3. *The operational level* - Experiments used to analyse operational consequences of C2S effectiveness. "Models" at this level consist of game situations or discussions involving senior naval officers.

In order to make development of models and experiments in each of these domains traceable, a step-by-step approach for modelling is followed, but not spelled out in detail except for the C2S level model.

An idealistic view of the modelling approach applied is illustrated in Figure 2.1. Stages of this approach are:

1. *Problem definition* - Overall model requirements and description of system boundaries and relations to C2 subsystem models. Definition of the kind of conclusions that are to be drawn from experiments. Important properties and different measures associated with these are defined based on the problem definition.
2. *Establish formal model requirements* - What should be represented in the formal model, and how should this formal model be expressed?
3. *Development of a formal model* - An unambiguous formal description of the system is developed, stating elements in the model, interactions between these, and a description of the model's environment.
4. *Development of simulations/experiments* - The formal model is implemented as an executable computer program, in a simulation tool, or as other types of experiments (e.g. with model elements represented by human decision makers within an artificially generated environment).

In reality this process is, of course, not as straight forward as illustrated, and new ideas and ways to look at the problem are likely to be conceived during all steps of this process, thus initiating a new cycle of model redevelopment

as indicated by dotted arrows in Figure 2.1. In other words, an iterative approach is inevitable.

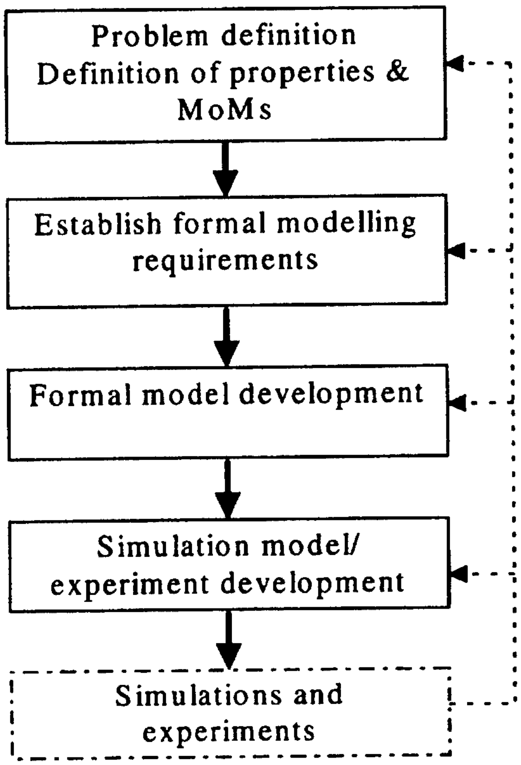

Figure 2.1 Modelling approach

This approach applies to hierarchy development as well, as described in the next chapter.

3. Overall model hierarchy

Due to the nature of the different levels, from operational effectiveness to bits and bytes of communication systems, it is necessary to divide the problem into a hierarchy of problem areas. One approach, illustrated in previous chapters, separates the separates the sub system level and the operational level from the C2S level.

This division originates from the common organisation of MoMs in a three level hierarchy consisting of Measures of Force Effectiveness (MoFEs), Measures of Effectiveness (MoEs) and Measures of Performance (MoPs).

- MoFEs are measures of the degree of mission success
- MoEs are measures of how a C2S performs one or more of its functions within an operational environment
- MoPs are measures of the performance of sub systems within the C2S

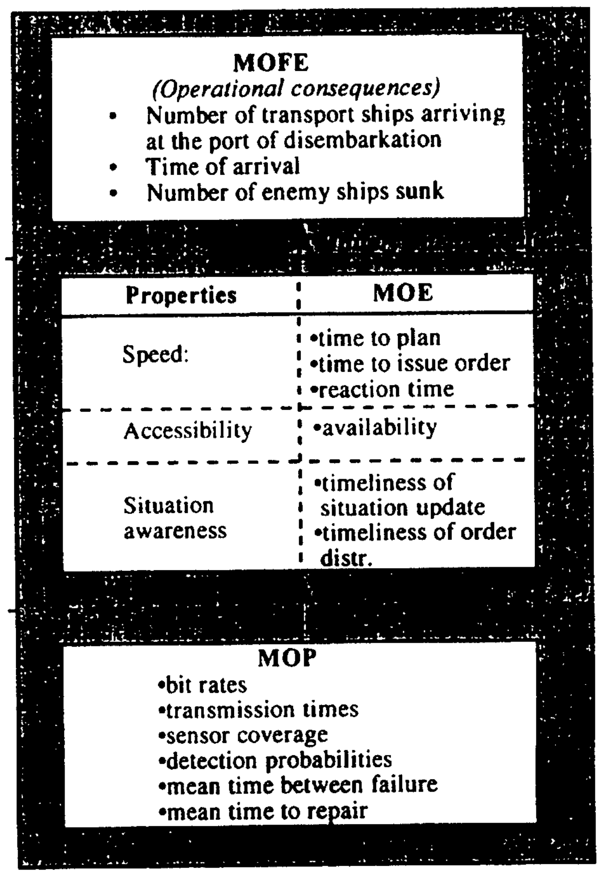

Figure 3.1 Examples of measures of merits at different levels. MoEs presented are connected to desired C2S properties.

A set of MoMs combined with model requirements and a clear understanding of the problem domain guides design of the models. MoMs make demands with regard to which parts of the C2S that are most important to represent in the models and the levels of detail.

In Figure 3.1, examples of MoMs are given at the sub system level, at the C2 level and at the

military operational level. The figure also displays the connection between MoEs and desired C2S properties.

The overall method for conducting experiments with the hierarchy of models is first to find the values of MoPs by using sub system level simulation models. Then these MoPs are used in an C2S level model. Experiments with the C2S level model give, in collaboration with war games and scenario discussions, the values of MoEs and MoFEs.

In following chapters the stages of model development are applied to the three levels of the model hierarchy starting with low level sub system models.

4. Sub system level models

Sub system analyses may be used in two different contexts. First, they may be used as standalone analyses with the purpose of comparing different sensor, information or communication systems.

Second, in the wider context addressed in this paper, the purpose of sub system models and simulations is to provide aggregate parameters to C2S level models.

Some examples of relevant MoPs for this purpose are:

- Bit rates
- Transmission times
- Sensor coverage
- Detection probabilities
- Mean time between failure
- Mean time to repair
- Technical vulnerability

Examples of sub system level analyses performed are:

- Transmission capacity and vulnerability studies of the Norwegian Digital Defence Network, providing MoPs for communication between shore-based elements of the naval C2S.
- Static coverage studies for national and NATO shore-based radio systems. MoPs concerning ship-shore and shore-ship communication are determined by these studies.
- Dynamic simulations of sensor coverage for satellite based, airborne, seagoing and shore-based surface sensors in chosen scenarios quantify MoPs for all types of sensors.

5. C2S level models

The approach to model development at the C2S level is basically problem oriented. This implies that one should:

- Understand factors influencing the problem prior to model development
- Focus the analysis directly towards the problem
- Tailor model to answer the problem

The aim of this approach is to minimise effort in detailing different parts of system descriptions and concentrate on fundamental properties of system alternatives related to the analysis performed. Hopefully, this will lead to less complex models with relatively easy interpretations of simulation results.

Following the modelling approach in chapter 2, steps of the model development for the C2S level are given in chapters 5.1 - 5.5.

5.1 Problem definition

The first step in the model development process involves establishing a problem domain and

identifying model requirements. It is important to make sure that the model adapts to the problem domain on an early stage in the model development process. This assumes good and detailed knowledge about the C2S and a clear understanding of C2S boundaries.

The aim of the model is to enable an assessment of C2S effectiveness by connecting quantitative MoMs to C2S behaviour. MoMs are defined prior to model development, because they direct how the C2S is modelled.

The aim of the modelling process outlined in this paper is to create a model enabling calculations of C2S effectiveness. Thus, MoEs become the most important measures, because they measure how well C2Ss perform in an operational environment.

C2 elements to be included in the model are the maritime part of the shore-based joint operational level and tactical level command elements (CTGs/OTCs and their staffs). Systems used by these C2 elements, such as communication systems, information systems and information sources under direct control of these C2 elements are also to be included.

Elements in the system environment interacting with elements inside the system boundaries are: Joint, land and air command elements of the joint operational level; Land and air assets co-operating with the maritime tactical level; Maritime units subordinate to tactical commanders; Civilian services.

Another important aspect is that performance studies of sub systems described in chapter 4 are to provide necessary parameters for the C2S level model. The relationship to these studies must be addressed in an early stage of the modelling process.

5.2 C2S properties and MoMs

In order to quantify C2S behaviour, MoEs should be founded on a set of desired C2S properties, which are deduced by following a top-down approach starting with naval tasks and the naval operational concept focusing on manoeuvre warfare and indirect operations.

This guides design of the C2S by making demands with regard to performance of the C2S. Following this approach three main system properties are deduced. These are: Speed, accessibility and situation awareness [NATO Panel 7, 1994]. Based upon these properties, MoEs are defined in order to quantify to what extent C2Ss analysed display these properties.

Examples of MoEs on the C2S level are:

- Time to plan
- Time to issue order
- Reaction time
- Availability
- Redundancy
- Timeliness of situation update
- Timeliness of order distribution
- Completeness, correctness and accuracy of information

5.3 Formal model requirements and methods

Formal C2S level models are designed to be unambiguous documentation of aspects chosen to be included in the simulation model and thus tools to aid the development of simulation models.

Traditionally, a functional perspective has been used in model development. That is, functions and their input-output relations are in focus during model development.

However, a functional perspective during model development has several drawbacks. For example, when a model is refined, the principle

of dynamic system decomposition is violated, by functions being decomposed without preserving state and behaviour within the boundary of lower level functions. As a result, the model structure becomes rigid, and inevitable modifications introduced as model development proceeds are not kept local to parts of the model.

By employing an object oriented perspective, these drawbacks are alleviated and a more flexible model structure is achieved, thus facilitating modelling of alternative systems. In the object oriented perspective, system structure and interaction between system components are defined before functions and information flow between them.

As the model is refined and modified throughout the modelling process, extensions and modifications are kept locally within the object classes.

An object oriented perspective is applied in the model approach discussed here.

A graphical syntax/notation is also a wanted in order to facilitate internal communication in the project during development.

5.4 Formal model development

Given properties, MoMs and formal model requirements and methods for modelling C2, a formal description of the system is developed.

UML [Lee, Tepfenhart, 1997] is a standard language for OO software development describing the model in different views: E.g. object view, functional view, and dynamic view.

A possible extension to UML would be to include role models showing interaction between the objects in different roles, i.e. in different settings. This may already be part of UML since it has been planned to be included for some time.

An agent model will most likely be able to represent proactive aspects better than a pure OO model.

Another choice of language considered is Colored Petri Nets. This is a language designed for expressing extended state-diagrams (concurrency, data structures, times and stochastic aspects). CPN contains only one composite view with focus on the functional/dynamic aspects, and in comparison to UML, objects are less explicit. Implementation of an executable simulation model from the formal model is uncomplicated in CPN, and the difference between the formal model and the simulation model would be of less importance than in the other languages.

5.5 Simulation model development

In order to quantify the properties of the C2S, the formal model is implemented as a discrete event simulation model.

C2 Scenarios developed from operational scenarios comprise "sequences of events" that trigger C2 processes in the C2S. Examples of processes are development of plans, distribution of orders etc.

The aim of the simulation is to quantify how well the C2S performs its tasks in an operational setting, and the importance of each quantitative measure will be interpreted according to an operational context generated by war games and scenario discussions.

Experiments with the C2S level simulation models are conducted closely related to operational level experiments, and are described in the next chapter.

6. War games

In order to reach the objective of assessing operational consequences of C2S alternatives it is necessary to connect MoEs to MoFEs. This is

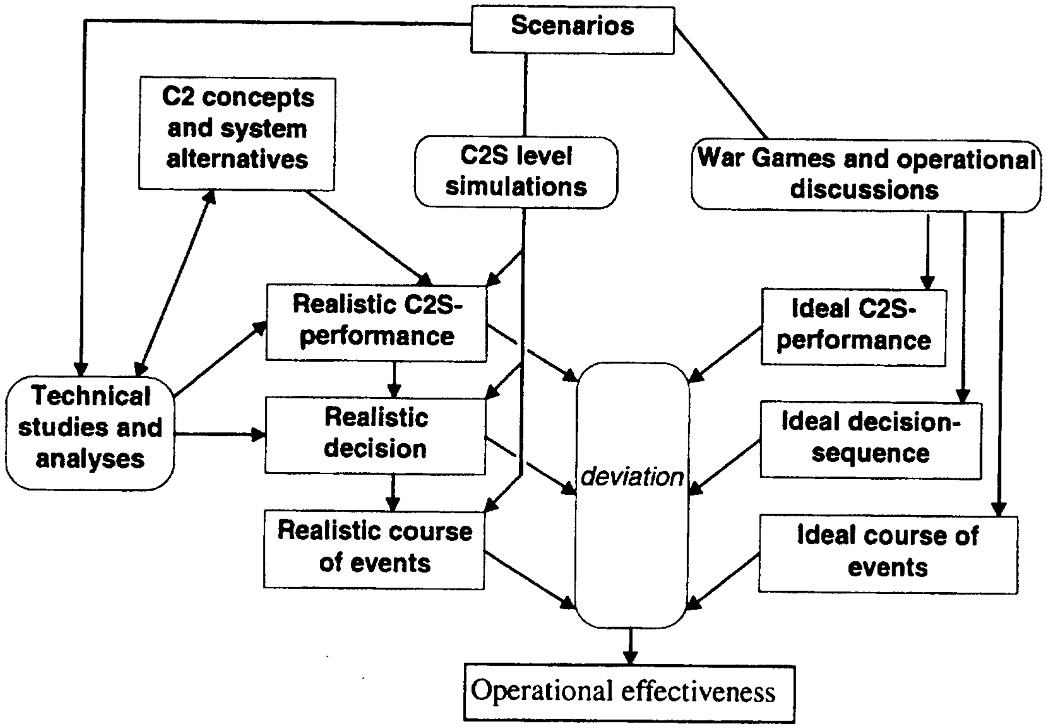

Figure 6.1 Use of scenarios in assessment of operational effectiveness

one of the major challenges in this cost effectiveness analysis.

Examples of MoFEs are:

- Number of transport ships arriving at port of disembarkation
- Time of arrival
- Number of enemy ships sunk
- Delay of enemy operation
- Other operation dependent success criteria

To determine the values of these MoFEs for a particular C2S alternative, war games and scenario discussions are applied. The main idea is to compare sequences of decisions produced by a candidate C2S with sequences of decisions produced by an "ideal" C2S. This is illustrated in Figure 6.1.

The "ideal" C2S performance is established by war games and scenario discussions involving senior naval officers. "Ideal" in this context indicates that the only performance limitation is inherent delays in decision and information processing by elements included in the system, and all other parameters are kept optimal.

In other words the system is surrounded by a zero-friction C2S, characterised by following properties:

- Enemy C2 warfare (including electronic counter and counter-counter measures) is ineffective
- Own communications are working, are impossible to jam and has no inherent delays
- Own information is correct and complete
- Necessary competence and accessibility is available in all own staff functions
- Instantaneous processing of own requests to superior command

- Necessary decision support systems are available
- Own surveillance assets are capable of complete and continuous surface and air coverage over the entire area of interest

Subsurface surveillance is not made "ideal" as this would seriously interfere with the operation concept of submarines.

Enemy intentions are in general also kept secret, in order to drive the decision process, and assumed intentions provided by own military joint intelligence cell is the only piece information available apart from the current maritime picture.

The performance and the actual sequence of decisions of a candidate system are determined from simulations of models as outlined above. Combining them with the "ideal" sequence enables assessment of operational effectiveness of C2S alternatives.

7. Discussion

The modelling approach presented relies on some well-known methods, such as decomposition of models and MoMs in a hierarchy, employment of an object oriented perspective in modelling, use of sub system models to quantify MoPs, and use of aggregate values of MoPs as parameters in a C2S level model.

The particular scheme for using a C2S level model complemented with war games and scenario discussions is novel. To our knowledge there is not much work addressing these aspects of C2S effectiveness studies.

The main remaining issues are connected to:

- incorporation of decisions, and related measures, into the model
- representation of information and decision quality
- details in the connection between C2S level simulations and scenario discussions

These issues are expected to be resolved by following the iterative approach described.

8. Conclusions

In this paper we have presented steps of model development within a framework for effectiveness analysis of naval C2S. The approach has been outlined in an on-going study and some examples and experience gained have been presented.

The method is a holistic approach to the problem of effectiveness evaluation of C2Ss. To our knowledge there are few published methods concerning the integration of the different levels of detail in such analyses.

It is somewhat premature to state the feasibility of this modelling/simulation approach, due to lack of utilisation.

Still, we believe that the approach will be highly useful, and so far we have seen that the approach itself raise important questions about the interconnectedness of C2 effectiveness studies that probably would have been obscured using a more system oriented approach.

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SAS-OO2 COBP Summary Measures of Merit

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OVERVIEW

- Objectives
- Definitions
- Characteristics
- Types
- Framework
- Challenges / Issues
- Recommendations
- Conclusions

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Objectives

- Comparison of alternate systems or solutions
  - replacement systems or components
  - determination of most cost-effective approaches
  - assessment in new or unexpected applications
- Establishment of standards, bounds of performance
- Identification of potential weaknesses
- Analysis of effectiveness of training
- Evaluation of effectiveness of human decision making
- Assistance in requirements generation and validation

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MORS Definitions

- MoFE - Measures of Force Effectiveness
  - Measures of how a force meets mission objectives
- MoE - Measures of Effectiveness
  - Measues external to C2 systems
- MoP - Measures of Performance
  - Measures of attributes of internal system behaviour
- DP - Dimensional Parameters
  - Properties or characteristics in physical entities

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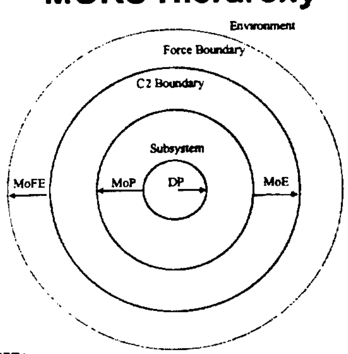
MORS Hierarchy



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Levels of Evaluation

- Goals (mission objectives) - Environment
- Functions and sub functions
- Tasks
- Structure / Interfaces
- Physical Entities

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Characteristics of Measures

- Reliability
  - representation of precision, and repeatability
- Validity
  - internal: causal relationship between variables
  - construct: measure objective, and only objective
  - statistical conclusion: results are robust with sufficient sensitivity
  - external: extent to which results could be generalized

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Types of Performance Measures

- Time based
  - time to perform a task
  - rate of performing tasks
  - time to react to events
- Accuracy based
  - precision of performance
  - reliability of performance
  - error rates
  - quality of decisions

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Framework

- Establish evaluation environment
- Define evaluation goals
- State context, assumptions, constraints
- Define domain - MoFE, MoE, MoP, DP
- Identify particular measures
- Specify measures
- Establish scenario or stimulus
- Establish data collection means
- Pilot test, revise measures and procedures
- Conduct the tests, debrief and analyze

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Division Performance Measures

- Two sets
  - monitoring tasks
  - planning tasks
- Two types
  - speed
  - accuracy
- Three levels
  - performance of headquarters as whole
  - performance of individual cells
  - performance associated with tasks

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Functions

- Planning
  - analyzing directives, factors
  - determining courses of action
  - producing plan
- Monitoring
  - receiving, verifying information
  - assessing impact of information
  - collating and organizing information
  - organizing, sending, and recording information

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Planning Measures

- Times to perform planning tasks
- Information Exchange in Planning
  - identify impacts on originator and recipient
- Planning task processes
  - identify tasks that create difficulties
- Quality of plans
  - assess tactical merits

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Monitoring Measures

- Internal message exchange between cells
- Comprehension of tactical situation
- External message exchange: volumes, times
- Alteration of plans

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Challenges / Issues

- Linkage of DP-MoP-MoE-MoFE
- Interpretation of measures
- Environmental components
- Reliability and validity
- Uncertainties - scenario, model, outcomes
- Human-in-the-loop
- Cost and convenience
- Modelling

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Recommendations

- Plan with clear objectives
- State assumptions, constraints
- Formally assess reliability and validity
- Concentrate on MoE and MoP
- Incorporate MoM data gathering into system design
- Include Subject Matter Experts in assessments
- Retain data as benchmarks for future comparison

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Conclusions

- No single measure or methodology exists for assessing overall effectiveness of C&C
- A multi-method, multi-phase approach is necessary

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On a Modular Concept for Command and Control in Simulation Models

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Introduction

This paper describes a principle architecture for the modelling of command and control in simulation systems. It focus on the definition of modules to represent command and control, reconnaissance and communications independent from an actual command level.

Hereby, command and control, reconnaissance, communications and effective entities - i.e., atomic elements within the simulation systems modelling the objects that act, interact, move and are victim of attrition - are clearly divided and grouped within respective modules. The communications module builds within this the interfaces connecting all other elements.

General Tasks of the Modules

The general tasks of the modules can be summarised like follows:

The in the introduction defined effective entities are used to model the physical and technical basic processes, i.e. movement, attrition, etc. They just receive orders that tell them what to do and act and react on them as predefined within the entities taking into account the actual perceived situation. On the chosen level of abstraction the entities receive orders and change their own as other status parameters respectively. This is the part of the simulation model application developers focussed on until recently.

Using a command and control module enables the application developer to model a command post or another element on the battlefield, the receives and generates orders, demands and situation reports. This module is the main topic with this report.

The reconnaissance module gets orders and generates situation reports. To be able to do so, it groups atomic entities that are able to observe their environment with or without sensors in order to discover the status parameters of the other entities and inform respective command and control modules by predefined reports.

Every order, demand and situation report must be transported by - i.e. passed via - an incarnation of the module communications. This module receives orders, demands and situation reports and deliver them, perhaps modified due to incoming information operations like jamming or introducing false reports or viruses changing the content of the data packages etc., from the source to the target.

Command and Control Modules

The following figure 1 shows the principle interfaces and data flows of a command and control module.

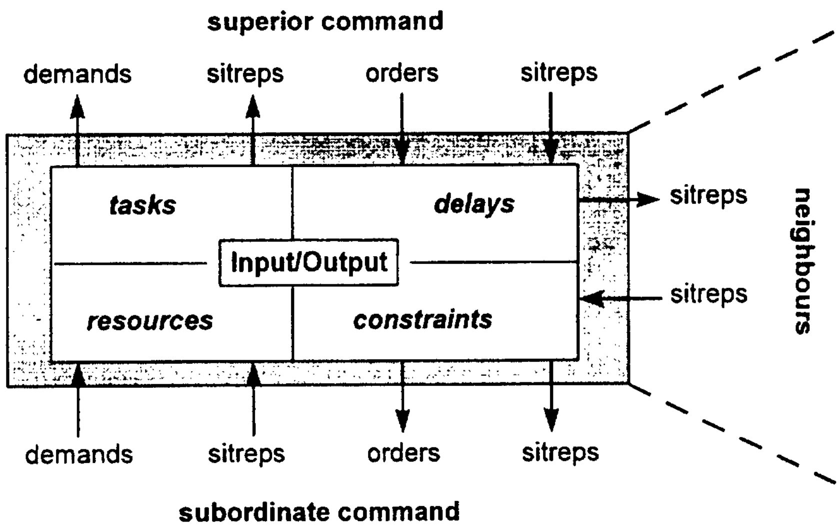

Figure 1: Command and Control Module

Each command and control module can communicate in principal into three directions:

- Superior commands are informed about the own perceived situation using predefined situation reports (sitreps). If a tasks cannot be fulfilled with the own available resources it is furthermore possible to put a demand. In the other direction the command module is informed by the superior command by further situation reports and - naturally - gets its orders from the superior command.

- Neighbours are informed and inform themselves about the respective perceived situation using predefined situation reports. Demands for help must follow the chain of command and can therefore not be placed directly.

- Subordinated commands are informed and inform themselves about the respective perceived situation using predefined situation reports. Furthermore, orders can be given and demands can be received.
  However, if the modelled command post is the last one in chain of command having only atomic simulation objects as subordinates, these objects belong to the modules reconnaissance and/or effective entities. In this case, orders can be given and - in case of reconnaissance - situation reports can be received.

The incoming situation reports are the basis for the perceived situation of the respective command post or element. Each element having to make decisions therefore must be an incarnation of a command and control module with an own perceived situation.

The incoming orders are the basis for the tasks the commended unit have to fulfil.

Therefore, within the command and control module, the process of planning and decision making aims at reaching the given objectives with the available resources and the given constraints. However, respective time delays have to be taken into account before further actions can be taken. The results of these processes are demands at the superior and orders to the subordinate commands.

Up to now, the command and control module is just a blackbox. The following chapter deals with the interior architecture of the module.

Command Post Structure and Organization

The definition of the respective command post structure and organization is crucial for command and control. Each command post - or better said each planing and decision making element within the simulation, is defined by the comprised centres and cells, the respective resources and the tasks that have to be performed.

Each centre or cell, e.g. the fire support co-ordination centre or the recce supporting cell, is moreover defined by the subtasks it has to perform, the resources being necessary and available for each task, the time delay when working on a task, the results and the constraints (which results from other cells must be considered or are necessary, to whom are the results passed, etc.).

Therefore, the structure and organization can be seen as a definition for a constraint workflow. Figure 2 shows the principle. The shown example can be interpreted as follows:

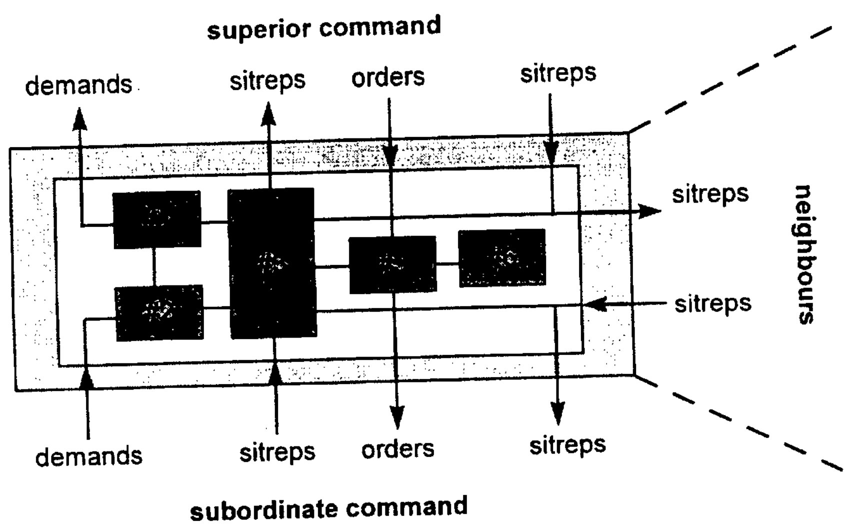

Figure 2: Command Post Structure and Organization

All situation reports are handle by cell #3. Furthermore, cell #3 has to take the actual orders into account, which are handled by cell #5. Cell #6 is responsible for the protocol of incoming and outgoing orders and situation reports. Cells #1 and #2 handle the demands dependent on the actual perceived situation and the given objectives.

The structure of the command post therefore is defined by the number and type of centres and cells, the organization is defined by the constraints respective the workflow.

As each cell is well defined by the interfaces, the processed data and the result, legacy systems can be used fulfil special tasks already modelled before.

Using this approach it is therefore possible to wrap a given G2 simulation receiving and generating situation reports and a respective perceived situation and include it in the operation centre of a command and control module. Furthermore, this general approach defines one common architecture valid for all command levels, although structure and organization are highly command level dependent.

Communications

As mentioned earlier in this paper all interchanges of orders, demands and situation reports must be transported by communications modules. The communications modules receives the data to be delivered. Inside this communication blackbox has to be computed, when the message arrives, how the message arrives (understandable, usable, destroyed or jammed), how information operations influence the process of delivery and its result etc.

Figure 3 shows the communication module as a blackbox.

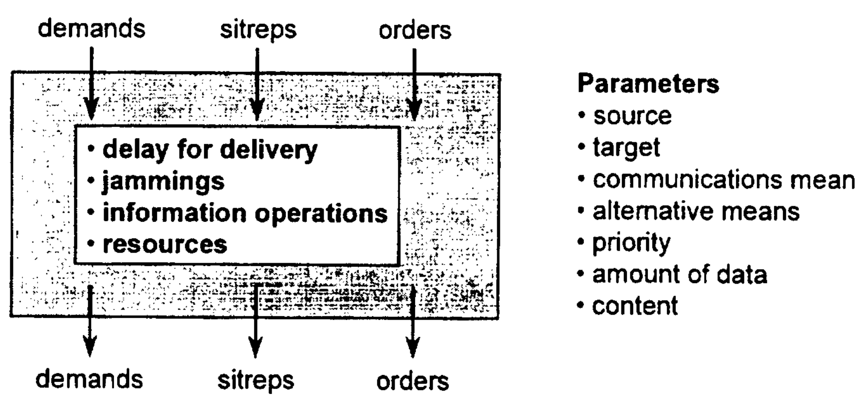

Figure 3: Communications Module

In a first approach, just the delaying time can be computed. In following versions all described parameters have to be taken into account. Again, it is possible to reuse legacy algorithm using wrapping means in order to have the appropriate interfaces.

Composition of the Modules

Combining all modules within a simulation systems it is now possible to distinguish clearly between the physical and technical processes on the one hand, and the modelling of planing and decision making - including human behaviour - on the other.

The simulated objects on the battlefield being very strong connected with the modules "effective entities" and "reconnaissance" model the physical and technical processes. Furthermore, the resources of all modules are connected to this level, so that it is possible to compute the effects of attrition on this resources. Therefore, resources can be observed by reconnaissance elements on the one hand or even be killed or destroyed by effective entities on the other.

All communication between the technical elements and modules modelling the process of planing and decision making use the communications module or modules. Within this it is possible to vary between high aggregated (e.g. only time delay) to high detailed communications models (e.g. channel saturation).

The planning in decision making process is modelled by command and control elements as described in the previous chapters. Figure 4 gives an example of the general composition.

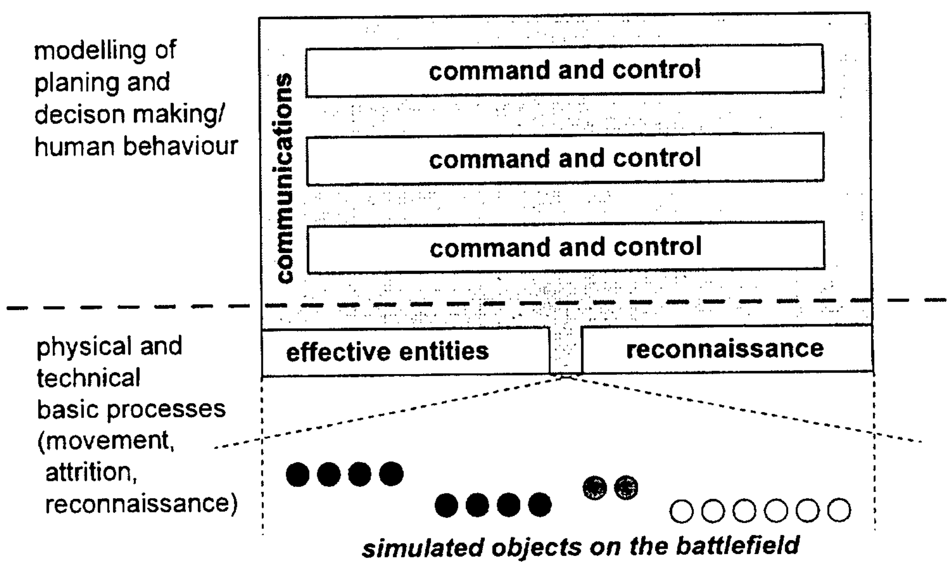

Figure 4: Composition of the Modules

As all modules comprise well defined interfaces, it is furthermore possible to migrate from the simple modular system to an HLA-based system (e.g. with a federation for each command post), a Web-based system and/or a man/real command post in the loop system.

Summary

The purpose of this paper is to present a concept for a modular approach for modelling command and control in combat simulations models. It is not intended to give ready to implement solutions.

However, the approach chosen offers the possibility to integrate detailed models on all levels into a highly scalable and configurable family of modules with well defined interfaces and tasks. In addition, all presented modules are reusable in the sense that they can be integrated into different adequate combat simulation models using the well defined interfaces.

They can be seen as a crucial element within a simulation repository.

A Meta-Language for specifying the Command & Control Processes

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Introduction

This paper will give a general description of the basic ideas, concepts and the methodology chosen to design and implement a meta-language for specifying the ordering af force units including a suitable representation of the Command, Control, Communications and Information (C3I) processes, which forms the basis for the ordering of forces. The meta-language presented here has been incorporated in the land combat model JOHANNES developed at Danish Defence Research Establishment (DDRE). The name *Ordrogram Language* is used to designate any meta-language used for specifying the ordering of force units. This specification for each force unit is called the *Ordrogram* for that unit.
So in other words, this paper will give a general description of the Ordrogram Language implemented in the JOHANNES model.
Furthermore, som illustrative results will given in order to show some of the capabilities of the JOHANNES model. From a study on different options for the set of longer range intelligence gathering systems the time when a major critical dicision was taken and the total losses to own forces for the different options will be presented.

The JOHANNES model is a deterministic time stepping descriptive land combat model which can calculate the outcome of any given scenario with specified C3I processes. Thus the model is not prescriptive, neither using optimization nor Artificial Intelligence. Development of the JOHANNES model began in 1984 with the aim of making it possible to analyse land combat at the division/corps level. It was from the outset recognized that the C3I processes form an integral part of combat when the purpose is to study tactical and operational questions at division/corps level. The JOHANNES model represents forces at 3 force levels. For own forces (named Blue) it is usually : Division(s), Brigades and at the lowest level Battalions and independent Companies - when necessary a unit may consist of a single system eg. a sensor system such as a drone or UAV (Unmanned Arial Vehicle).

In a traditional land combat model direct fire weapons have a representation of the detection process which supplies targeting information to the individual weapon system. In addition sensor systems with the sole purpose of acquiring intelligence/information about enemy units is possibly also represented. Furthermore, a constructive simulation model must have some means of controlling the units in a given scenario, ie. letting the units move, act and change state or posture.
In short it can be said that the C3I processes makes the connection between the raw intelligence data acquired by weapon and sensor systems and the control of the force units.
In the development of the JOHANNES model the C3I processes are considered to include :

- Sensor / weapon systems gather intelligence (information about enemy units).
- Intelligence and information about own situation is at intervals forwarded with a delay to the superior force and maybe other force units.

- Each commander establishes his own intelligence picture and assesses own situation.
- Each commander takes decisions and thence give orders to own unit and subordinate forces.
- These orders controls the deployment and employment of the forces.

This is conceptually similar to eg. Boyd's OODA-loop (*Observe, Orient, Decide, Act*) and Lawson's : *Sense - Assess - Generate - Select - Plan - Direct.*

At DDRE it has for many years been considered as advantageous when building constructive simulation models to define and construct an Ordrogram Language to be used to specify the force units and how they react in a given scenario. This makes it more easy to adapt the model to new scenarios or new tactics.
The new development is the inclusion of concepts for the C3I processes as an integral part of the JOHANNES combat model and at the same time defining new language constructs in the Ordrogram Language for specifying the C3I processes. Thus the Ordrogram Language for the JOHANNES model is used to describe the communications, intelligence gathering, decisions, orders, actions etc. of all the force units in a scenario.
The implementation of the Ordrogram Language interpreter in the JOHANNES model is fully object-oriented so there is in principle no limit on how complex decisions and orders can be specified. The interpreter can also be used to make changes to the Ordrograms during a simulation run. Furthermore, the model includes an Ordrogram-writer which can output the Ordrograms. When the writer is activated interactively it also indicates the actual state of the decisions and which orders actually is active ie. orders controlled by conditions which are true at that time.

The concept of a meta-language for specifying the ordering of forces is used for most virtual simulation model, eg. the many versions of the IDAHEX model where movement of forces is ordered by the MOVE order. In case of a virtual simulation model the meta-language does not need any control concepts such as conditional and loop constructs nor any representation of the C3I processes because these aspects are taken care of by the 'live'-part of the simulation. The orders being issued to these models can simply be thought of as being time stamped by the simulated time at which they were entered into the model. Furthermore, when these time stamped orders are recorded on files then in principle the virtual simulation model can be made to read the orders and 'replay' the simulation without human intervention, so that one may say that the model has become a constructive model for this particular ordering of the force units.
By including control concepts such as conditional and loop constructs into the meta-language it becomes possible to let the ordering of forces depend on the tactical situation thereby letting the individual forces intelligently adapt to the battle situation. A meta-language for ordering of force units must have some kind of control concept in order to be considered a Ordrogram Language.
Finally, by incorporating into the model a representation of the whole Command & Control loop processes and defining suitable meta-language constructs for specifying these processes then it becomes possible for a constructive simulation model dynamically to establish an intelligence picture of all simulated commanders, determine the decisions made by the commanders and then simulate the consequences of the orders issued to subordinate units. The result is a constructive combat model where the Command & Control loop processes are an integral part of the battle dynamics and specified as input to the model.
Because the Ordrogram Language for a constructive simulation model contains as a subset the

orders for a similar virtual simulation model, then a constructive combat model utilizing an Ordrogram Language can in principle also be used as a virtual simulation model. This is the case for the JOHANNES model, although it has not been implemented in a very user-friendly way.

The methodology of using an Ordrogram Language was also used in the predecessor (CASSANDRA) to the JOHANNES model and the origin can be traced back to the CLAG system developed at Shape Technical Centre (now NC3A) and reported in STC TM-414. The TRIAMOS model developed at IABG, Germany also uses a simple Ordrogram Language to specify the organisational structure and movement and posture of the units. The IDAHEX model could be said to use the most simple Ordrogram Language if one considers the use of time stamping as a control construct. An common advantage of using an Ordrogram Language is that the complete description of the ordering is specified in a file which thus fully documents the doctrine and tactics. In case of the JOHANNES model the Ordrogram file includes the full description of the scenario and all the C3I processes including the decision making and ordering of the force units. Thus it is possible to specify scenarios with different doctrine and tactics by making appropiate changes to the Ordrograms of the force units in the scenarios.

An alternative way of incorporating the ordering of force units into a constructive simulation model is to hardwire the orders into the code of the implemented model. A structured way of doing this is to have dedicated programming modules calculating the ordering of force units. These modules are usually termed Tactical Decision Rules and may in part be based on look-up tables for the choise of commander decisions. The more flexibility one builds into the input parameters and look-up table for Tactical Decision Rules the closer one gets to the flexibility of using an ordrogram language and in the end one might just as well go for using a dedicated Ordrogram Language which will make the whole scenario description including the commander decisions more readable. In the JOHANNES model the whole scenario description including user defined names of forces, decisions and ordering of force units with defined orders like ATTACK and DEFEND and conditions like LOSS and STRENGTH is a more readable documentation than numerical data in a parameterfile to Tactical Decision Rules. This also makes it easier to verify that the specified decisions are in accordance with agreed doctrine and tactics. Furthermore, as stated above there is in principle no limit on how complex decisions and orders can be specified.

This paper will focus on describing the Ordrogram Language including the language concepts defined for specifying the Command, Control, Communications and Information (C3I) processes of land combat in the JOHANNES model. Some general information about the models representation of the C3I processes will also be given.

Basic Ordrogram Language concepts

The basic constructs of an Ordrogram Language is :

- Orders for specifying the type of movement for force units ie. whether it is attacking, defending or retreating like MOVE, ATTACK and DEFEND.
- Orders for specifying the tactics for a force unit, eg. rules of engagement or how artillery fire is used.
- Orders for specifying the state of a force unit, eg. how it is deployed or the fraction of weapon systems kept in reserve.

- Conditions like LOSSES to own force unit or STRENGTH of an observed enemy unit.
- Operators like the logical operators AND and OR.
- Conditional control constructs like IF and loop control constructs like WHILE.

The orders is exactly the same as if the meta-language would have been defined for a virtual simulation model.

The conditions of the Ordrogram Language is defined so that for a force commander of a given force unit the conditions only refers to intelligence and information available to that force commander, ie. it is impossible to specify conditions based on perfect information.

All Ordrogram Languages must have a conditional control construct like "IF <condition>". Furthermore, it is recommended to define some kind of 'block' construct whereby it becomes possible to specify that several orders is conditional on a single specified condition - and this also makes it possible to include other "IF <condition>" in a 'block' ie. it is possible to nest the conditional control construct. The JOHANNES model uses the character '>' to specify a 'block level' and due to the object-oriented implementation there is in principle no limit to the number of levels for nesting of conditional control.

It is possible to imagine several loop control constructs like "FOR <iterator> DO" or "WHILE <condition> DO". The JOHANNES model does not have any explicit loop construct but an implicit 'global loop' construct in the sense that at each time step the Ordrogram for every force unit is read completely 'from beginning to end' including an automatic updating of the specified complete intelligence picture and all binary decisions (see below). This concept of a 'global loop' of all Ordrograms at every time step has been chosen because the dynamics of combat including the available intelligence may change so much from one time step to the next time step that different decisions are taken, and the concept of a nested list of conditional controls within a 'global loop' makes it possible at any time step to update all decisions and easily letting changes in decisions change the ordering of force units irrespective of the orders issued to same units previously, ie. one does not have to specify all the allowed 'changes of state' for the ordering of forces.

Having explicit loop control constructs would be necessary if one defines that ordrograms are only read once for a complete simulation, so that the interpreter needs an 'ordrogram pointer' (like the computer concept of a 'program pointer') for each ordrogram to keep track of whereto the ordrogram has been read. In this case one may say that the 'ordrogram pointer' indicates the actual state of ordering for each force unit and it becomes necessary to specify all allowed 'changes of state'. Such a loop concept was implemented in the predecessor to the JOHANNES model. This was preferred at that time because the 'changes of state' were very simple ie. for each state there was usually only one successor state.

Having built the whole Command & Control loop into the JOHANNES model and noting the fact that changes in decisions may completely change the ordering of force units, it becomes clear that the concept of a nested list of conditional controls within an implicit 'global loop' is the best solution and it makes the specification of the ordering of the force units very flexible and much easier to specify.

Finally, The Ordrogram Language of the JOHANNES model do include constructs for controlling a sequence of 'states' like (fly out - reconnoitre - fly back home - refuel - fly out - and so on).

In the figures below used for illustrative purposes the conditional control construct will be omitted for simplicity. One may say that the conditional control construct is implied by the conditions and logical operators. Furthermore, the use of the implicit 'global loop' is assumed.

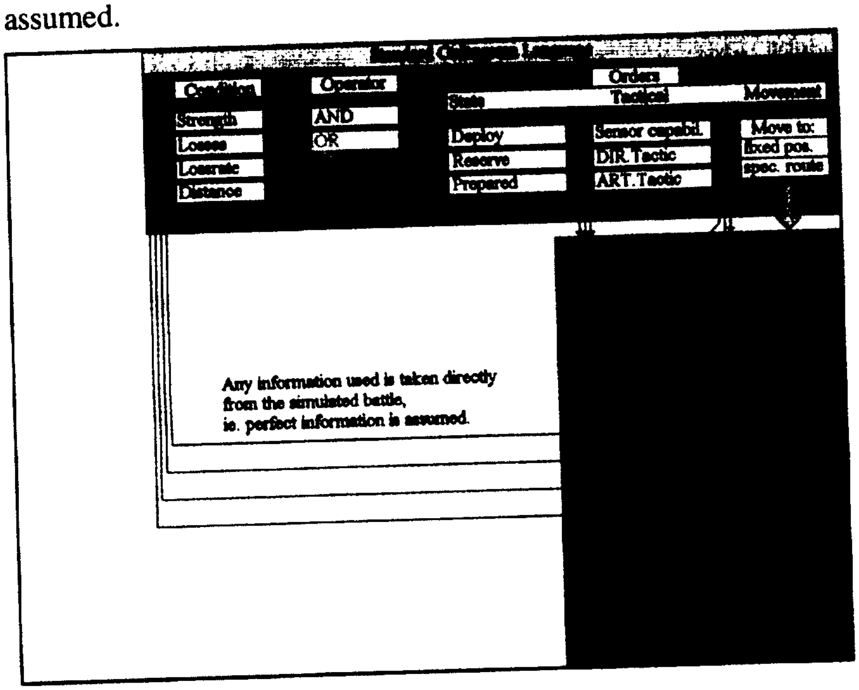


Figure 1. Concepts for a basic Ordrogram Language

The concepts of a simple Ordrogram Language in a basic combat model is illustrated in figure 1.

The lower right box with the weapon systems represents the force units. In order to emphasize the lack of a representation of the C3I processes the basic combat model does not represent dedicated sensor systems.

The upper box represents the ordering of the force units using an Ordrogram Language.

Note that if 'Conditions' and 'Operators' are omittet then one has the meta-language concepts of a virtual simulation model.

Basic concepts for Intelligence

In a standard land combat model direct fire weapons have a representation of the detection process which supplies targeting information to the weapon system. In many standard combat models sensor systems with the sole purpose of acquiring intelligence/information about enemy units is also be represented.

Having incorporated the capability of weapon systems of detecting the weapon systems of enemy units into the JOHANNES model the next step is to represent the collection and dissemination of observations about enemy units. This includes the transmission of observations from all sensor and weapon systems capable of making observations to the commander of the unit to which the systems belong. These observations then becomes pieces of intelligence. Each piece of intelligence is qualified by a timestamp and an accuracy measure and several pieces of intelligence about the same enemy unit are aggregated using a Kalman filter. A piece of intelligence may be used both as a condition for making a commander decision and for specifying the end position for a movement order. Furthermore, it has been decided that targeting information for artillery fire is treated separately so each piece of intelligence has additional parameters for artillery targeting specifying the positional accuracy (CEP) and time when the target position was observed. All artillery fire can only be directed at one or more observed artillery target positions ie. targeting based on perfect information is impossible.
A single <u>piece of intelligence</u> about an enemy unit contains the following information :

- The observed strength
- The observed position
- The accuracy of observation measured as a standard deviation of observed strength
- Time when the observation was made
- Estimated speed of enemy unit
- The observed position for observation used for artillery targeting
- Targeting locating accuracy for observation used for artillery targeting
- Time of observation for observation used for artillery targeting

A commander will transmit all his pieces of intelligence to other (usually superior) force unit(s) together with information about the capability of own force unit. The communication network for transmission of intelligence and information is qualified by a time delay which causes a (further) degradation of the accuracy of each piece of intelligence.

It is of cause necessary for the Ordrogram Language to have a state defining order that controls the time delays and the frequency at which one unit transmits its observations to other units, thereby making it possible to control these aspects dynamically based on the battle situation.

The processes for handling of observations as pieces of intelligence and can be regarded as an extension of the detection processes of the normal combat model. These processes are an 'internal' part of the model and done automatically by the model so that only the actual capability like time delay and quality loss is controlled by the Ordrograms. This is in contrast to the specification of how each commander establishes a complete intelligence picture and the commander decisions which is completely specified in the Ordrograms, ie. these processes are not simple extensions of the normal combat model, but can better be regarded as represented by extensions to the Ordrogram Language defined for the JOHANNES model. These processes are specified using defined new language constructs which will only influence the combat model as specified by orders in the Ordrograms.

Having incorporated dedicated sensor systems and the concepts and processes for handling pieces of intelligence in the combat model is illustrated in figure 2 (the conditions and logical operators in figure 1 will be part of *Decision Making*). Note that now it is possible to order a force unit to move to a position specified by a piece of intelligence ie. the observed position of an enemy unit.

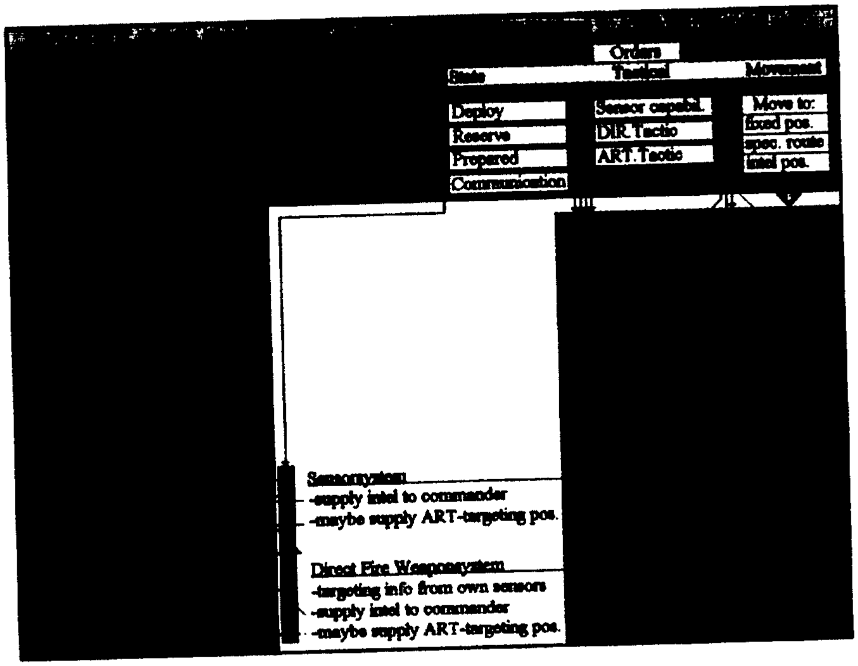


Figure 2. Combat model with representation of Intelligence

In figure 2 the still missing part of the Command & Control loop is shown as boxes. They are the representation of the *Situation Appraisal* ie. the establishment of a complete intelligence picture based on available intelligence/observations and the representation of the *Decision Making* which is based on the established intelligence picture and controls the orders issued to the force itself and subordinate force units.

Comparing the above with virtual simulation models it can be noted that modern virtual simulation models include similar representations of available intelligence to each commander and the boxes shown *Situation Appraisal* and *Decision Making* is exactly the functions performed by officers as players to virtual simulation models. These models must of cause have suitable Graphical User Interface capable of showing the available pieces of intelligence to each commander and as usual letting the officers input orders to the unit. Thus figure 2 is a good depiction of the similarities and dissimilarities between a modern virtual simuation model and a constructive simulation model incorporating a representation of the whole C3I loop processes and utilising an Ordrogram Language. Either the processes in the boxes are performed by real officers or will be determined by the model according to the specification in the Ordrograms.

Having come so far as depicted in figure 2, what remains is to define suitable Ordrogram language constructs which will enable the description of processes in the boxes shown ie. *Situation Appraisal* and *Decision Making*. These processes will be described in turn below although it must be realised that the language constructs for both had to be defined in conjunction because the constructs have to fit together and provide the necessary descriptive capability for specifying how decisions are made based on the established intelligence picture. Furthermore, the definitions of the orders of the Ordrogram Language had to be extended in order to be able to provide the necessary dependacies on these processes, eg. the positions to which a force unit is ordered can be specified relative to the established intelligence picture.

Concepts for Situation Appraisal

It was realised that Situational Appraisal ie. the establishment of a complete intelligence picture involved an interpretation of how the individual pieces of intelligence about individual enemy units fitted together in an overall enemy Order of Battle. This would be used eg. to estimate the total strength (including any unobserved units) of the enemy force and where the

enemy is concentrating his forces in a main trust axes of advance. The complete intelligence picture would then be the basis for commander decisions on employment and deployment / redeployment of own forces eg. counter attack.

It was decided that in order to represent an established intelligence picture it was necessary to define a language construct that enables aggregating the available intelligence about some specified enemy units. A single specification of this language construct is called a *piece of aggregated intelligence*. This language construct makes it possible to specify as many pieces of aggregated intelligence as might be needed to describe all the elements that makes up an established complete intelligence picture depending on the dynamic battle situation. Each element specifies a particular interpretation of how some enemy units fits into a postulated Order of Battle. The established enemy Order of Battle may depend on the available intelligence or battle dynamics. This can be described by specifying all the needed elements / pieces of aggregated intelligence for all likely interpretations of enemy Order of Battle and then specifying the decisions based on a particular interpretation as dependent on the conditions for making that particular interpretation (see further explanation below). An enemy thrust axes may be judged from the observed strength of one or more pieces of aggregated intelligence and different judgements can be taken care of in a similar manner as different interpretations explained above.

The aggregation of available intelligence from pieces of intelligence is done in a straight forward and matematical sound way. For each piece of intelligence two positional attributes are determined based on the available intelligence. One attribute is the position of the centroid ('centre of gravity') of the observed strength of the individual pieces of intelligence. The other atttribute is the position of the most forward piece of intelligence. Which of any number of positions is the most farward is determined in the following way. For each side of the simulation is specified a 'contour-map' which gives a measure of how far any given position is from 'homeland' so the position with the highest 'contour-map' value is said to be the most forward.
The movement orders of the Ordrogram Language has been defined such that it is possible to order a force unit to move to a position relative to one of the positional attributes of a piece of aggregated intelligence.

Concerning targeting information for artillery fire aggregation makes no sense because artillery fire is aimed at specific (sub-units of) force units. Instead, a piece of aggregated intelligence can be used to specify a target list in which case the artillery fire is divided among the specified enemy units depending on the observed strength, positional accuracy and a specified parameter for each piece of intelligence. The fire is of cause aimed with the positional accuracy of the available targeting information for each individual enemy unit being targeted. An ordrogram specified fire table determines the type of ammunition to be used.

In a similar manner as explained above pieces of information about the capability of own sub-ordinate force units can be aggregated using a language construct called a *piece of aggregated information*. This will not be explained further in this paper.

Concepts for Decision Making

Basically a decision is characterised by the conditions for making that decision and the consequenses (ie. the orders being issued) of making that decision. Put simply a decision is a

'binary' choise : either the decision is make or it is not made. It was realised that even though all decisions in principle could be broken down into a set of binary decisions then it would be much more flexible if one also had a language construct for a single decision with several possible outcomes.
Therefore the following language constructs has been defined for specifying the different types of decisions :

- Binary (Boolean) decisions, indicating whether a given decision is made or not. These decisions are usually evaluated at each timestep and a time delay for making the decision is incurred. One such decision could be to commit a reserve force which could be dependent on losses suffered by own force units engaged in combat and/or whether these units have lost too much ground, ie. the most forward unit has receded behind a critical line.
- One-of-many decisions. The decision is represented as an integer value chosen among a defined set of values. This concept can be used to e.g. select one particular cause of action among several actions or when one cause of action is composed of a sequence of 'sub-actions' in which case each 'sub-action' must be executed in turn. Any change of value for these decisions is completely ordrogram controlled and may include time delays, e.g. a 'sub-action' or event is initiated when the preceeding 'sub-action' or event is completed or when the force commander judges that the tactical situation demands it. One example could be a reconnaisance unit which has to reconnoiter several areas in succession or just have to operate according to a sequence of 'states' like (fly out - reconnoitre - fly back home - refuel - fly out - and so on).
- Several-of-many decisions. This concept may at the same time select zero, one or several causes of action among a list of actions. For each cause of action a value-of-merit is calculated (based on available intelligence and information). Then at ordrogram controlled points in time these decisions are updated, i.e. the model determines which of the many cause-of-action are chosen based on e.g. the value-of-merit, a required minimum value-of-merit (may be determined dynamically) and a maximum number of simultaneous causes of actions. This type of decision can be used e.g. to specify commitment at division level of several reserve units for support or reinforcement depending on the tactical situation in different roles or at different places in the battlefield.
- Choose one-of-many forces. This concept selects zero or one force unit among a list of units. The decision is either based on intelligence about enemy units or information about subordinate units. The choice is made at ordrogram controlled points in time. For each force unit in the list of choise a value-of-merit (e.g. observed strength of enemy force) is calculated. The force with the highest value-of-merit is chosen, except when a required minimum value-of-merit is not fulfilled in which case no force is selected. This *choose-one-of-many forces* construct together with the value-of-merit for the chosen force can be used to indicate one cause of action for the *several-of-many decisions*.

When it states that e.g. making a decision is ordrogram controlled it means that it is controlled by the Ordrogram for a particular force, i.e. it is specified in the Ordrogram under what circumstances (e.g. an attribute of a particular item of the complete intelligence picture) the decision is taken. This means that the decisions and the points in time at which the decisions are taken are fully dynamical and specified in the Ordrogram.

In short the concepts for decision making is a rule based description of the decision making processes using dedicated defined language constructs in the Ordrogram Language.

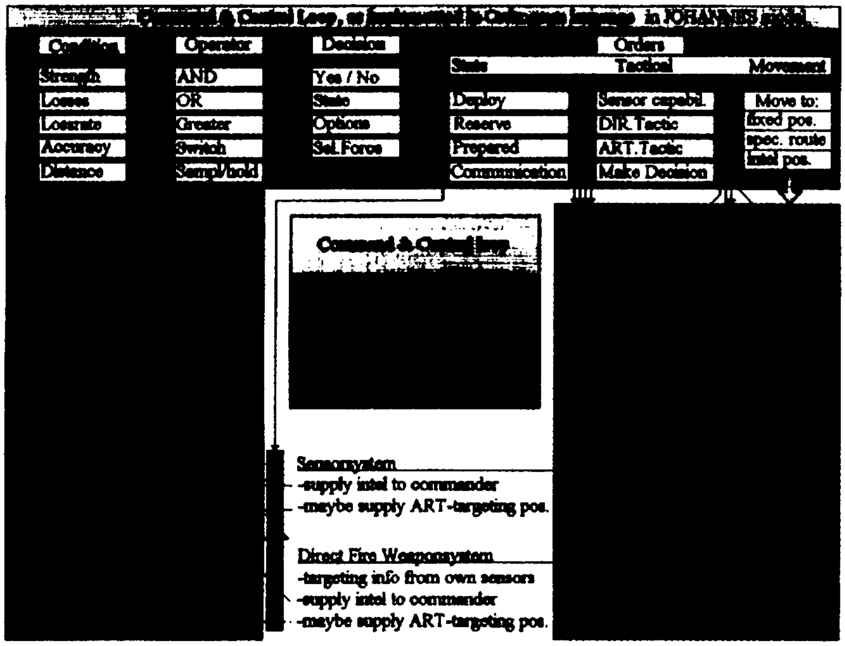


Figure 3. Concepts for Ordrogram language with constructs for the whole Command & Control loop

Having completed the Command & Control loop with the above described model concepts and language constructs for *Situational Appraisal* and *Decision making* the combat model with the Ordrogram Language is illustrated in figure 3.

Note the addition of tactical orders controlling when decisions are made. Note also that the conditions are based on the intelligence picture and not on assumed perfect information.

By having defined easy understandable Ordrogram 'keywords' for orders and conditional terms and the scenario developer specifying appropiate mnemonic names for the pieces of intelligence used to describe the situation appraisal and names for the decisions which may be made under specified circumstances, then it becomes possible for analysts and analysis customer (military officers) together to 'read through' the Ordrograms of all the forces in a scenario and understand how the simulated commanders establish a complete intelligence picture, the commanders decisions under specified battle conditions and the subsequent ordering of subordinate forces. This makes it comparable easy to verify that the specification of the commander decisions and tactics used in the scenarios for a given study is realistic and according to doctrine.

It is not possible to include random errors in the decision making processes, but it is possible to include specified decision making errors under specified circumstances. One example could be that as long as the quality of the intelligence picture measured in some way is below some threshold then a commander will misinterpret the enemy Order of Battle and consequently make wrong decisions, eg. deploy an armoured reinforcement unit in the wrong place. It is possible in the model output to check when any decision is made and trace the effect on the following battle outcome (see example below).

Ordrogram example

In order to examplify the Ordrogram Language a small example will be given. Please note that it is not possible to explain all the details in this paper - and even less so all the many detailed features of the Ordrogram Language.
When the syntax of the Ordrogram Language was defined due consideration was taken to readability and ease of implementing the reader and interpreter for the language. One result of these considerations is a 'procedure'-like notation also for logical operators like AND (ie.

AND(logic.express1 , logic.expess2)). Furthermore, due to the concept of a 'global loop' for all Ordrograms some operators for timing aspects has been defined, eg. ONCE(logic.express) which initially is False but when the parameter is true it will become True and keep this value afterwards. Finally, in order to make it easier to identify the different types of Ordrogram entities the name of entities is defined to be delimited by different characters eg. " for force units, # for routes, ? for piece of aggregated intelligence, % for piece of aggregated information about own force units and : for decisions.

As an illustration of the Ordrogram Language an example with a troop force (brigade) commanding a subordinate force unit (battalion). The force unit may be thought of as a reserve force to be committed either in defence if an enemy break-through is imminent or in offence if own forces are judged capable of a counter attact.

The Ordrogram for the brigade is :

```
TRP="25 BDE" "25" "A BDE"  30.0   155.5  34.5   100.0 100.0
    ?E DIV A?     "11 REG/1"  "12 REG/1"  "13 REG/1"  "14 REG/1"
    ?E DIV A-1?   "11 REG/1"  "12 REG/1"
    ?E ART TGT?   "15 RAG/1"  "16 RAG/1"  @ 10.0
    ?E DIV A-1X?  "12 REG/1"  "21 REG/2"  "14 REG/1"
    %A 1+2% #2.0 "1 BTN /25"  "2 BTN /25"
    :FORWD 3:    LOSS(%A 1+2%,0.25)
    :MISTAKE:*   ONCE(AND(:FORWD 3:,NOT(ACCURACY(?E DIV A-1?,100.0))))
    :WITHDR 1:   LOSS("1 BTN /25",0.75)
    :WITHDR 2:   LOSS("2 BTN /25",0.75)
    :3 DEFEND:   OR(LOSS("1 BTN /25",0.70),LOSS("2 BTN /25",0.70))
    :ATT-OK:*   AND(NOT(:3 DEFEND:),AND(:FORWD 3:,ACCURACY(?E DIV A?,50.0)))
    :3 ATTACK:   AND(:ATT-OK:,STRENGTH(?E DIV A?,2500.0))
    >   DEPLOY   0.5  10.0  0
    >   SENSOR   =B1SEN=
    >   INTEL    49.99   0100   005   015  10.0
    >   INTEL    -0.001  1.0  005  0
    >   DECISION   001  0  0  -1
    >   MARCH    10.0  #ROUTE 25#   0.0 0.0
    >   IF  ARRIVED
    >>      DEFEND
    >   IF  AND(:WITHDR 1:,:WITHDR 2:)
    >>      RETREAT 10.0  2.5   50.0 50.0
```

The Ordrogram for the battalion is :

```
AFD="3 BTN /25" "3/25" "A BTN"  30.0   100.0 100.0  11.1 0.0  "A TANKBTN"
    >  DEPLOY  1.5  3.5   0  =B1FORM=
    >  SENSOR  1  4.5  0.9   0.0
    >  SENSOR  2  2.0  0.8  -0.1
    >  SENSOR  3  2.0  0.3  +0.1
    >   INTEL   29.99   030   005   015  10.0
    >   INTEL   -0.001  1.0  005  0
    >   DECISION  015  0  0  0
    >   DEFEND
    >   IF :FORWD 3:
    >>      SENSOR  1  7.5  0.9   0.0
    >>      MARCH  30.0  ?E DIV A-1?*  5.0   0.0 -10.0  030
    >>      IF  :MISTAKE:
    >>>        MARCH  30.0  ?E DIV A-1X?*  5.0   0.0 -10.0  030
    >>      IF  :3 DEFEND:
    >>>        SENSOR  1  2.5  0.9   0.0
    >>>        TCONTACT  5.0  ?E DIV A-1?.  5.0   0.0 -10.0
    >>>        CBATTERY  2  3  1.0  ?E ART TGT?
```

```
>>>        ARTTACTIC  0.05  0.1  015  0.1  0.0  15.0
>>>     IF  NOARTTGT(?E ART TGT?,1)
>>>>       ARTTACTIC  0.05  0.5  015  0.1  0.0  12.0
>>      IF :3 ATTACK:
>>>        SENSOR  1  2.5  0.9   0.0
>>>        SENSOR  2  2.0  0.2  -0.1
>>>        INTEL   29.99   030   015   015  10.0
>>>        ATTACK  15.0  5.0   %A 1+2%*  2.0
>>>        GSUPPORT  1  3  2  0.0 0.2  0.1  "*"
>    IF  LOSS(0.75)
>>      RETREAT 10.0  2.5   @ "25 BDE"
```

A short explanation of the ordrograms is given in the following.

Explanation of the brigade Ordrogram :

The commander of the brigade "25 BDE" will decide as follows.

- If the known total losses of "1 BTN /25" and "2 BTN /25" is greater than 25% then he will move his reserve force "3 BTN /25" forward to a position 'in front of ' the assessed forward regiments of an enemy division (:FORWD 3:).
- If the accuracy of the intelligence about these forward regiments, ie. "11 REG/1" and "12 REG/1" has a standard deviation of more than 100.0 MilVal after he has decided to move his reserve force forward then he will misjudge the force structure (Order of Battle) of the enemy division (:MISTAKE:). He will judge "12 REG/1", "21 REG/2" and "14 REG/1" to be part of the first echelon of the enemy division.
- If either of the forces "1 BTN /25" or "2 BTN /25" is known to have suffered more than 75% losses then they will be withdrawn (:WITHDR 1:) and (:WITHDR 2:).
- If either of the forces "1 BTN /25" of "2 BTN /25" is known to have suffered more than 70% losses then the force "3 BTN /25" is ordered to defend as far forward as possible (:3 DEFEND:).
- The force unit "3 BTN /25" is ordered to make an attack (:3 ATTACK:) if it has been moved forward (:FORWD 3:), but not ordered to defend (:3 DEFEND:), the intelligence accuracy of the aggregate intelligence?E DIV A? has a standard deviation of less than 50.0 MilVal and the observed strength of the same aggregate intelligence is greater than 2500.0 MilVal.

The brigade "25 BDE" will move forward following route #ROUTE 25# and after arriving at the end point of this route it will make a stationary defence until the brigade commander has decided to withdraw both "1 BTN /25" and "1 BTN /25" (:WITHDR 1: and :WITHDR 2:), at which time the brigade will retreat to a rear position. The ordrogram specifies also such parameters as deployment area, time delays and implicit sensor characteristics.

The battalion "3 BTN /25" will act on the orders given by its superior troop unit "25 BDE" as follows.

- If it is ordered to move forward (:FORWD 3:) then it will make an administrative movement to a position 10 km 'in front' of the known position of the centroid of the forward regiments ("11 REG/1" and "12 REG/1") of the enemy division (aggregate intelligence ?E DIV A-1?) forecasted to 30 minutes into the future. Furthermore the range of the implicit sensors (eg. patrols) is increased to 7.5 km.
- If the brigade commander misjudges the Order of Battle of the enemy (:MISTAKE:) then the ordered position will be based on an aggregate intelligence in which the intelligence about "11 REG/1" is replaced by intelligence about "14 REG/1" and "21 REG/2".

- If the force unit is ordered to defend as far forward as possible (`:3 DEFEND:`) then it will make a tactical movement towards the most forward position of the forward regiments (`"11 REG/1"` and `"12 REG/1"`) known to the superior brigade (aggregate intelligence `?E DIV A-1?` of the brigade) until contact with enemy forces after which it stays at the same position. The indirect fire weapon systems will be used for counter battery fire with the aggregate intelligence `?E ART TGT?` of the superior brigade as the target list. The targeting data will be taken from the intelligence about `"15 RAG/1"` and `"16 RAG/1"` of the brigade and fire will be allocated more heavily against `"16 RAG/1"` as specified by a priority factor for the aggregate intelligence. Normally fire will only be allocated against targets located with a CEP less than 0.1 km If no targets fulfill the specified artillery firing requirements then fire will be allocated against targets located with a CEP less than 0.5 km.
  Finally, In this case the range of the implicit sensors (eg. patrols) is reduced to 2.5 km.
- If the force unit is ordered to attack (`:3 ATTACK:`) then it will follow the route of the centroid of the aggregate information `%A 1+2%` of the superior brigade containing the brigades knowledge about the the forward battalions `"1 BTN /25"` and `"2 BTN /25"`.
  The indirect fire will be used as general support to the force unit itself.
  Finally, the time delay for transmitting pieces of intelligence is increased from 5 minutes to 15 minutes and the capability of the implit sensors is reduced (range to 2 km, and maximum size observed of enemy units is reduced from 80% to 20%).
- If the total losses exceeds 75% then it will retreat to the actual position of its brigade (`"25 BDE"`).

Note that the ordered positions for the force unit refers to aggregate intelligence and aggregate information belonging to the superior brigade, thus the positions are based on the available intelligence and information of this brigade `"25 BDE"`, and not on that available to the force unit itself. This means that the ordering is completely controlled by the superior brigade. Likewise, the targeting data for indirect fire if used as counter battery fire is also based on available intelligence of the superior brigade.

Model application

The JOHANNES model has been used in a major national study of longer range sensor systems for the danish army. The scenario is a meeting engagement of one Blue division with 2 brigades in front and 3 enemy divisions of which 2 are in front and the third division is in the army second echelon. The Blue forces used current danish doctrine and tactics. In order to play the effect of surprise the initial Blue advance is based on an assumed main thrust axis of enemy divisions which are shifted sideways compared to the actual enemy thrust axes, so that Blue needs to shift the thrust axes of the forward brigades when intelligence identifying the need for a shift is available.

The study included the analysis of a Base Case and several cases with different options of longer range sensor assets. The cases show here is Base Case and 6 options. The options are denoted by two characters, the first character indicates whether artillery locating radars are used (A) or not (-), the second character indicates three different employment options for longer range airborne sensors (UAV's).

In this study the following measures-of-effectiveness were recorded to compare the different options of longer range sensor assets :

- Time when sufficient intelligence for identification of the 2 front enemy divisions.

- Time when sufficient intelligence for identification of enemy corps reserve ie. 3rd division.
- Time when sufficient intelligence for identification of the 2 front enemy divisions being inside Blue brigade area of responsibility.
- Time when sufficient intelligence for identification of enemy corps reserve being inside Blue brigade area of responsibility.
- Time when Blue has recognised that Blue brigade forces are off axis relative to the main thrust axis of the front enemy divisions and therefore decides to change the route of advance for Blue brigade forces.
- Time when Blue commits his reserve brigade.
- Time when enemy commits his reserve division.
- Time when enemy reserve division gets in contact with Blue forces. This point in time is called the 'critical time'.
- Own total losses at 'critical time'.
- Enemy total losses at 'critical time'.
- Force exchange ratio at 'critical time'.

Two examples of analysis results will be presented.

Figure 4 shows the time when Blue has realised the need to shift the thrust axis of brigade 1 and decided to do so for all the cases. It can be seen that the maximal improvement is more than one and a half hour, which can make a lot of difference in a meeting engagement. Note that the decision is made earliest for the third employment option for longer range airborne sensors, and latest for Base Case and the second employment option.

Figure 5 shows the total losses (weighted over all weapon types) for own forces for all cases. Note that the significant differences in own losses is only due to variations in available longer range sensor assets. Note that the total losses is smallest for the case using artillery locating radars and the first employment option for longer range airborne sensors.

Figure 4, Time when Blue decides to change thrust axis for Brigade 1

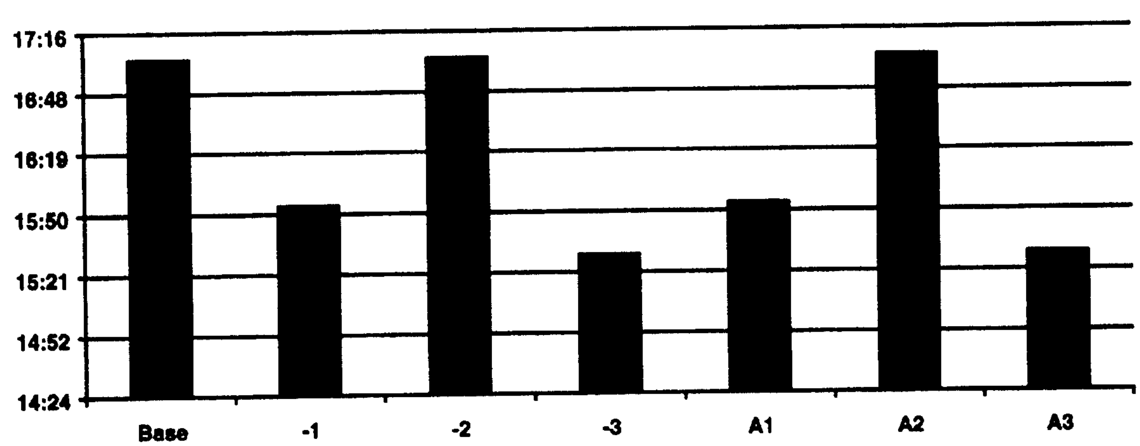
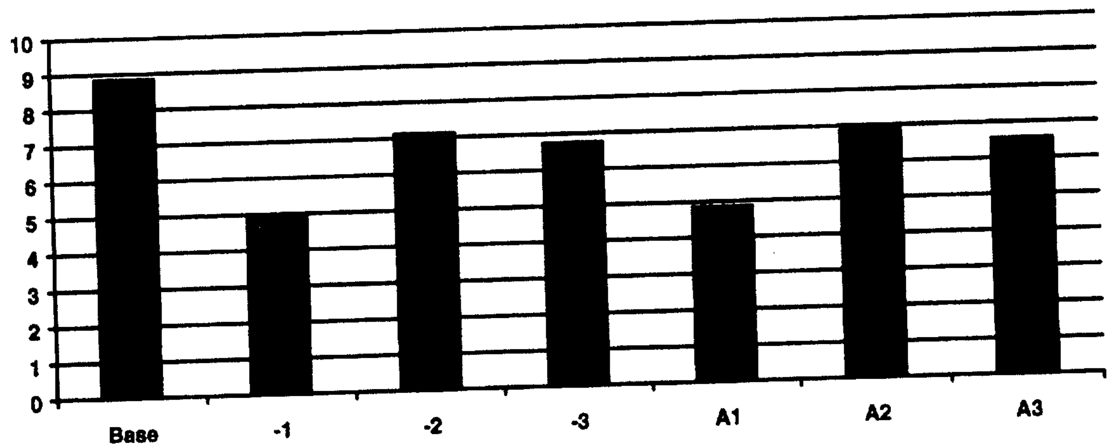


Figure 5, own Losses (weighted sum of all weapon types)



For each particular study one should select the measures-of-effectiveness appropiate for the study in question. The two study areas : *sensor systems* and *C3I systems* are closely related and all the above mentioned measures-of-effectiveness are also relevant for studying C3I issues.

The JOHANNES model is quite flexible and can produce a large variety of output data relevant for a combat model with an integrated representation of the C3I processes at the level of aggregation of this model (10's of Mega-Bytes if required). This include force status, detailed intelligence picture, detailed loss calculations, summary of loss calculations for forces and types of weapon systems, total/average measures-of-effectiveness for types of weapon systems including inflicted losses and ammunition consumption etc. . Furthermore, the Ordrogram Language includes orders for logging when things happen (eg. a decision is made) and logging some data of the complete intelligence picture.

Model limitations

With respect to the representation of the C3I processes the JOHANNES model has the following limitations :

- Forces are represented at 3 force levels. The main limitation is that the transmission of intelligence and information can only incur time delays twice.
- The transmission of intelligence and information between two forces is specified as a time delay (speed) and loss of quality. The actual network and means of communications is not represented. There is no capacity limit on the transmissions. Keeping in mind that the model is deterministic the inclusion of a capacity limit would require an algorithm for determining which transmissions of pieces of intelligence and informations would not be accomplished.
- The model has at the moment no built-in representation of reduced communication capacity nor of reduced decision capability due to the destruction of C3I units or headquarters. In a given scenario it is possible using the Ordrogram Language to play a specified increase in time delay (or no communication at all) between specified force units

and increased decisionmaking time delay under specified dynamic tactical situations (eg. high losses to certain units).

- Due to the level of aggregation analysis issues relating to a single or few weapon systems can not be studied but the effects can be represented. This limitation is not applicable for individually operated sensor systems like UAV's.

Finally, it should be noted that the model is designed as a descriptive model calculating the battle outcome of a specified scenario including a specification of the C3I processesses as described above. The model does not make any form for optimization nor include any expert system algorithms. Neither does the model have any built-in concept for evaluating which of several battle outcomes is the optimal - this judgement has to be made by military judgement considering all the relevant measures of effectiveness.

Conclusion

This paper has given an overview over the basic ideas, thoughts, and the chosen methodology and concepts for representing C3I in the JOHANNES land combat model. Reasons for chosing a methodology of defining an Ordrogram language have been given and the chosen language constructs for describing the C3I processes has been explained in general terms.

One way of thinking of an Ordrogram Language is to start with the meta-language defined for a virtual simulation model and then add new language constructs enabeling the specification of the Command & Control loop processes ie. a description replacing the real commanders in virtual simulations.

The advantages of using an Ordrogram Language for constructive combat models with an integral representation of the C3I processes like the JOHANNES model are :

- The description of the scenario including the C3I processes is done using a specification language ie. an Ordrogram Language which is specifically designed for that purpose. Decision making is specified using a rule based description.
- The simulated force units can be ordered fully dynamically depending on the 'actual' combat situation, eg. a commanders established intelligence picture.
- The description using this Ordrogram language fully documents the scenario and C3I processes used in a given analysis. Having a complete documentation of the syntax and semantics of the Ordrogram Language is sufficient for checking and verifying the complete scenario description. There is no need to reference a documentation of the source code of the computer model.
- The description using this Ordrogram language is much more compact and 'understandable' than a listing of the source code of a computer model. This makes it a lot easier to ensure an error-free scenario description and thus verify the scenario description including the specification of the doctrine and tactics used.
- It is easy to trace when changes happen eg. a decision is made and why the decision is made, this makes it easy to verify that the simulated commanders acts according to doctrine and tactics.
- Using an Ordrogram language it is fairly easy to change the force structure, tactics and simple parameters in the C3I processes (eg. time delays) and document the differences. Changing doctrine or making more fundamental changes to the C3I processes may require more extensive changes to the specified ordrograms of the force units. But even so, the changes is made using a specification methodology suited to the task - you do not need to do some reprogramming of the computer model - and still, the documentation is better.
- The JOHANNES model is a constructive simulation model, but can in principle also be used as a virtual simulation model.

In national studies it was found desirable that one can be certain that a good representation of national doctrine and tactics is used in a study and that the same basic doctrine and tactics is used when comparing the measures-of-effectiveness for different options (ie. equal basis for comparison), and this is ensured by the chosen representation of the C3I processes.

In studies the model has been able to show complicated cause / effect relationships which beforehand was far from obvious, but which became evident when examining the model results.

The ideas and concepts presented in this paper can also be useful in the context of Computer Generated Forces. Here the main issue is that the description of the decisions for all force unit should take into consideration all the possible battle situations for the units. Though, it must be admitted that it will probably not be possible to specify an Ordrogram for all force units that is completely general irrespectively of envirronmental factors such as terrain and climate. It is hypothesized that the main reason for this is that the space-time aspects of the art of decisionmaking at the brigade/division level is too complex to be put into some general algorithmic description.
Anyhow, using a dedicated Ordrogram Language with suitable language constructs such as in the JOHANNES model it is possible to describe the dynamic C3I processes of force units including intelligence gathering, decision making and ordering of subordinate forces in a given scenario. Furthermore, this description can be modified and extended as the need arises, eg. changes in own or enemy doctrine and tactics. It is also possible to make the changes necessary in order to accommodate the changes from one scenario to another specific scenario.
When making some test runs for a new scenario it is comparable easy for a military commander to identify a situation in which he would have made a different decision and what orders would then be given to subordinate units. The ordrograms for the new scenario can then be modified or extended accordingly. The Ordrogram Language of the JOHANNES model does in fact have such flexibility that it is possible to specify decisions and the ordering of force units completely general relative to the 'actual' space-time dynamics of the battle. This is in deed possible for rather simple tactics, but the experience has been that the art of combat decisionmaking at the division level does not restrict itself to simple and straight forward tactics. Furthermore, it must be realised that it is much easier to identify and specify commander decisions in concrete 'actual' situations than decisions to be valid in any arbitrary scenario.

Finally, the intension has been to show that it is possible to define and implement an Ordrogram Language which in a realistic way can represent the C3I processes. The Ordrogram Language of the JOHANNES model makes it possible to specify commander decisions - both the conditions for making a decision and the control excerted by the decision eg. the position a force unit is ordered to move to - in a flexible and dynamic way based on the commanders complete intelligence picture which again is based on available intelligence.

Représentation du C3R dans un environnement de simulation orienté objet

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1 - INTRODUCTION

Le CAD (Centre d'Analyse de Défense) est un organisme du ministère français de la défense chargé de la réalisation d'études technico-opérationnelles au profit d'organismes étatiques.

Pour mener à bien ce type d'études, le CAD a développé de nombreux outils, parmi lesquels une structure d'accueil permettant la mise au point de simulations technico-opérationnelles.

Le but de cette présentation est de décrire la méthodologie mise au point par le CAD pour prendre en compte l'aspect C3R (Communication, ; Contrôle, Commandement, Renseignement) dans ce type de simulations.

Dans cet article, l'environnement utilisé par le CAD, ESCADRE, ainsi que la bibliothèque BABYLONE contenant les composants logiciels réutilisables développés par ce centre, sont d'abord présentés. Ensuite, la modélisation du C3R dans BABYLONE est décrite de manière détaillée. Enfin, le paragraphe suivant montre un exemple d'étude menée par le CAD, faisant intervenir un réseau complexe de communication.

2 - L'ENVIRONNEMENT ESCADRE

2 – 1 - Généralités

Afin de construire rapidement une simulation technico-opérationnelle permettant de mettre en jeu différents types de systèmes d'armes, le CAD a développé la structure d'accueil ESCADRE (acronyme d'Environnement de Simulation en Conception orientée objet et Ada pour le Développement et la Réutilisabilité des Etudes).

ESCADRE, utilisé au CAD depuis 12 ans, s'appuie sur une méthodologie de développement orientée objet, permettant une modélisation proche du monde réel qu'elle veut représenter.

2 – 2 - Caractéristiques

La structure ESCADRE favorise la réutilisation des composants logiciels, en offrant un cadre de travail composé :

- d'une méthode de conception orientée objet,
- d'un guide de programmation pour coder les composants à développer,
- de bibliothèques de services : interface graphique, statistiques, exploitation, préparation des jeux de données...

2 – 3 - Conception

Pour mettre au point une application sous ESCADRE, il faut d'abord identifier les différents acteurs intervenant dans le scénario retenu.

Chaque acteur majeur (par exemple, le radar, le missile sol-air , l'avion) peut alors être représenté par un composant logiciel particulier. Les composants, créés sous ESCADRE, peuvent être développés indépendamment les uns des autres. Ils peuvent ensuite être assemblés, sans modification, de façon à générer l'application spécifique à l'étude qui doit être menée.

Une fois les acteurs identifiés, il faut déterminer les interactions à prendre en compte. Cela se traduit par des échanges de commandes et / ou de données. Ces interactions peuvent être classées dans deux catégories complémentaires :

— l'échange direct d'informations entre des classes d'objets « parents » et des classes d'objet « enfants », c'est à dire entre des composants d'un même système d'arme. Les interactions de ce type sont dites « cognitives ».

— les échanges d'informations entre les classes d'objets distinctes (en particulier entre un système ami et un système ennemi). Ils se font par l'intermédiaire d'un mécanisme particulier, les « propriétés » ESCADRE. Chaque interaction entre classes d'objets distinctes correspond à une « propriété » unique, et est définie par un composant ESCADRE spécifique. Elle permet de définir un protocole d'échange entre des partenaires ne se connaissant pas. Ces interactions sont dites « aveugles ».

Les « propriétés » sont basées sur un principe client / serveur, représenté à titre d'exemple par la figure 1.

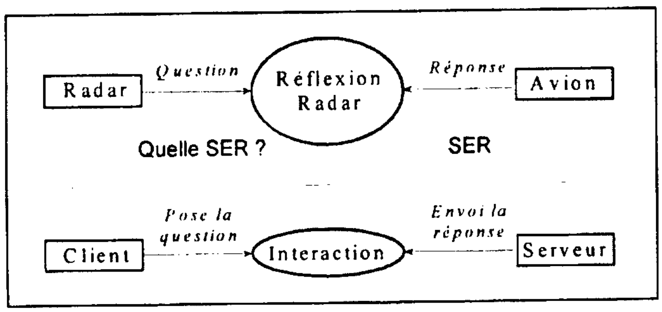


Figure 1 – exemple d'interaction entre objets

3 – La bibliothèque de composants logiciels BABYLONE

Le besoin de capitaliser les nombreux modèles, développés dans le cadre des différentes études technico-opérationnelles menées par le CAD, est rapidement apparu. C'est la raison pour laquelle une bibliothèque de composants logiciels, appelée BABYLONE a été créée.

Le but de cette bibliothèque est donc de réunir l'ensemble des modèles informatiques, développés sous ESCADRE, disponibles actuellement au CAD et pouvant être partagés par différentes applications.

Pour être introduit dans BABYLONE, un composant logiciel doit répondre à certains critères précis. Il doit être :

- réutilisable,
- cohérent avec ESCADRE et avec les autres composants (développement sous la même version d'ESCADRE par exemple),
- vérifié, validé,
- prêt à être intégré dans une application,
- documenté. Un manuel d'utilisation expliquant les principales caractéristiques du composant, le niveau de modélisation retenu ainsi que les hypothèses de modélisation doit être rédigé.

BABYLONE est une bibliothèque « vivante » qui s'enrichit constamment de nouveaux composants logiciels, en fonction des études conduites par le CAD.

4 – LA MODELISATION DU C3R DANS BABYLONE (SOUS ESCADRE)

4 – 1 – Introduction

Les études menées actuellement par le CAD font toutes intervenir des scénarios complexes dans lesquels les systèmes d'armes sont nombreux et variés.

Le maillage des différents senseurs des systèmes sol-air et sites de détection est rapidement devenu un aspect primordial dans les études, dont il a fallu tenir compte pour pouvoir fournir des analyses pertinentes.

4 – 2 – Modélisation du C3R - Méthode

Compte tenu des modèles déjà introduits dans BABYLONE et des services offerts par ESCADRE, la méthode la plus rapide et surtout la plus souple pour modéliser les communications à travers différents réseaux a été la création d'une nouvelle interaction (ou propriété avec la signification expliquée dans le paragraphe 2) entre objets.

Cette interaction a été appelée « ADS_DATA_LINK ».

Les informations échangées par les différents acteurs d'un réseau peuvent être par exemple :

- la position et la vitesse estimées de la cible détectée,
- la date de la détection,
- l'état de la piste : libre ou affectée (une piste est formée à partir d'un ensemble de plots corrélés et associés à une même cible).

L'approche retenue pour la modélisation du C3R permet de représenter d'une manière réaliste tous les échanges de données effectués dans un réseau de défense aérienne.

Selon le principe décrit au paragraphe 2, les clients de la propriété ADS_DATA_LINK sont les senseurs qui possèdent une information à faire parvenir à un ou plusieurs autres systèmes qu'ils ne connaissent pas a priori.

Par exemple, le client de la propriété peut être un radar de détection lointaine ayant détecté une cible. ADS_DATA_LINK offre le moyen d'informer de cette détection tous les systèmes, appartenant au même réseau de communication.

Les serveurs sont les systèmes qui veulent recevoir des informations provenant d'autres senseurs. Un exemple d'application mettant en œuvre un réseau complexe d'échanges de données est décrit dans le paragraphe 5.

Ces échanges de données se produisent aussi souvent que nécessaire, selon un mode asynchrone.

Chaque système d'armes possède son propre canal d'émission et peut recevoir des informations en provenance de plusieurs canaux.

Les caractéristiques du maillage retenu entre systèmes est décrit dans le fichier de données, qui fournit le scénario de l'application. Ainsi, chaque système d'armes définit son propre réseau de communication en y désignant les numéros d'identification des canaux qu'il veut recevoir.

4 – 3 – Introduction de la coordination

Grâce à l'interaction ADS_DATA_LINK, une coordination simplifiée, entre plusieurs systèmes d'armes liés par leur appartenance à un même réseau de communication, a pu être introduite.

En effet, à travers le réseau auquel elle est associée, une batterie sol-air peut recevoir une piste concernant une cible potentielle, détectée par un autre senseur. Les informations ainsi transmises contiennent une donnée fournissant l'état de la piste (la piste peut être libre ou

affectée). Ainsi, lorsque la piste est engagée ou poursuivie, la batterie sol-air sait que la cible a déjà été prise à partie par un autre système d'armes. Elle ne l'engagera pas, afin de se consacrer à une autre cible dont l'état de la piste est libre.

Ce type de modélisation, bien que très simple, permet d'éviter les problèmes d'« overkill », et ainsi de prendre en compte une coordination basique, qui a l'avantage d'être facilement intégrable dans un scénario même très complexe.

4 – 4 – Principales hypothèses

Les principales hypothèses concernant cette modélisation du C3R sont rappelées dans ce paragraphe.

Les délais de transmission de données sont des paramètres actuellement pris en compte : les informations envoyées par le client d'ADS_DATA_LINK ne parviennent au serveur qu'après un retard de transmission (ce paramètre est fourni dans les fichiers d'entrée de la simulation).

De même, les problèmes de saturation engendrés par un nombre trop important de messages reçus ont été considérés : chaque réseau possède un buffer de taille maximale; ce buffer déborde chaque fois que le nombre de messages reçus avant leur traitement dépasse sa capacité. Les messages supplémentaires sont alors perdus.

La charge de travail de l'opérateur du système d'armes occasionnée par la mise en réseau des senseurs n'est pas prise en compte. De plus, les erreurs éventuelles de transmission de données ne sont pas modélisées.

La fusion de données provenant de plusieurs capteurs est actuellement parfaite, mais le traitement de filtrage de pistes est modélisé.

Actuellement, la transmission des signaux entre les différents sites n'est pas modélisée. On considère cette transmission comme parfaite et non brouillée.

Mais la structure adoptée pour modéliser le C3R est suffisamment évolutive pour permettre la prise en compte des aspects puissance d'émission et présence de brouilleurs de communication lorsque ceux-ci seront modélisés et interviendront dans les scénarios.

4 – 5 – Architectures possibles

Tous les composants logiciels permettant de prendre en compte le C3R dans les applications sont disponibles dans BABYLONE.

Ils sont à présent utilisés dans de nombreuses études faisant intervenir des types de réseaux de transmission de données très différents.

La structure adoptée est suffisamment souple pour pouvoir modéliser des maillages de systèmes d'armes et de senseurs intervenant dans une architecture de défense aérienne totalement distribuée ou au contraire très hiérarchisée en matière de C3R.

Le chapitre suivant décrit une applications utilisant une architecture hiérarchisée en matière de C3R.

5 – EXEMPLE D'APPLICATION

L'exemple présenté dans ce paragraphe concerne la partie C3R d'une étude traitant de l'évaluation de l'efficacité d'une défense aérienne face à une attaque composée de missiles de croisière.

5 – 1 – Organisation de la défense - scénarios

Dans le scénario retenu, la défense est constituée :

- de systèmes de détection : radars de surveillance lointaine associés à des sites de détection, radars aéroportés, radars de surveillance des batteries sol-air,
- de centres de commandement et de contrôle : unités de contrôle élémentaire, unité de commandement global,
- de moyens d'interception des cibles aériennes : intercepteurs porteurs de missiles air-air, batteries sol-air tirant des missiles sol-air.

L'architecture de la défense est présentée par la figure 2.

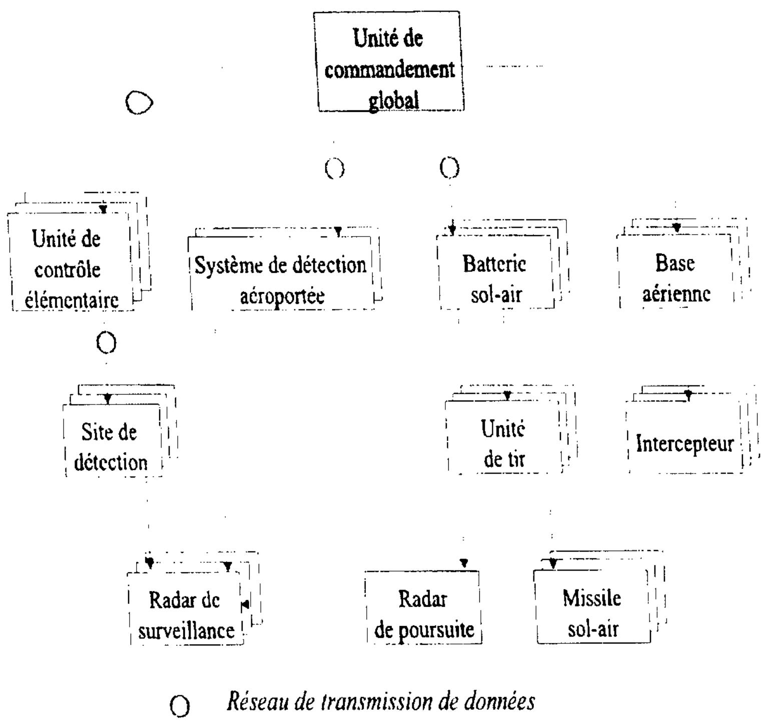


Figure 2 – Architecture de la défense

Chaque boîte représente un modèle disponible dans BABYLONE.

Les scénarios retenus dans le cadre de cette étude ont été mis au point et validés par des opérationnels exerçant leurs activités au sein du CAD. Ils prennent en compte de nombreux systèmes d'armes ainsi que leurs senseurs associés.

5 – 2 – Organisation de la simulation

La figure 3 montre l'organisation générale de la simulation, retenue pour mener à bien cette étude.

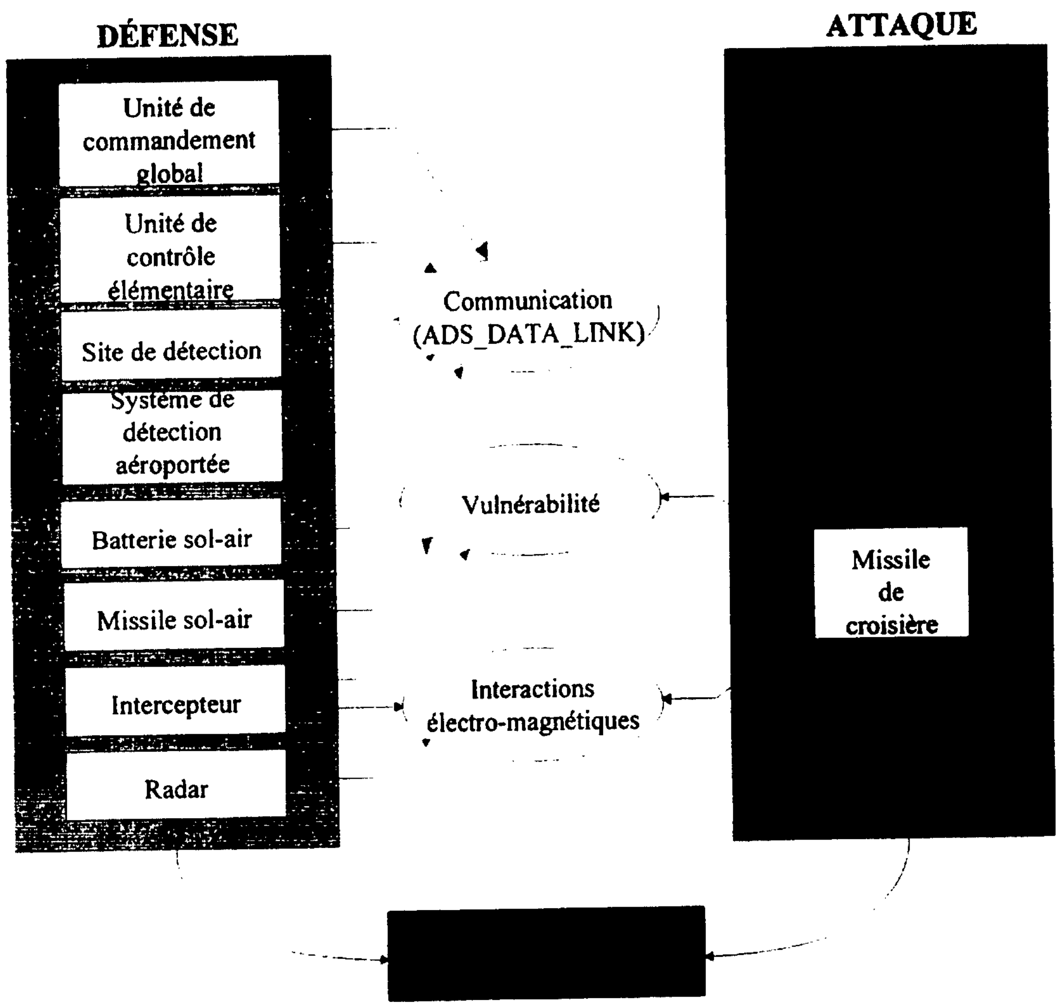


Figure 3 – Organigramme de la simulation

Comme dans la réalité, on constate que les camps attaque et défense sont bien séparés. Ils ne sont reliés que par les « propriétés » au sens défini au chapitre 2. Parmi elles, le schéma mentionne la « propriété » de VULNERABILITE, permettant d'avoir connaissance de la destruction éventuelle d'un missile de croisière par un missile sol-air ou air-air. De même, la « propriété » INTERACTION ELECTRO-MAGNETIQUE est utilisée pour les calculs de détection des cibles par des radars, quels qu'ils soient.

Ainsi, chaque camp utilise les échanges de données pour ses propres besoins. Contrairement aux propriétés de VULNERABILITE et d'INTERACTION ELECTRO-MAGNETIQUE qui interagissent entre les deux camps, la communication PAR ADS_DATA_LINK n'intervient que dans le camp de la défense.

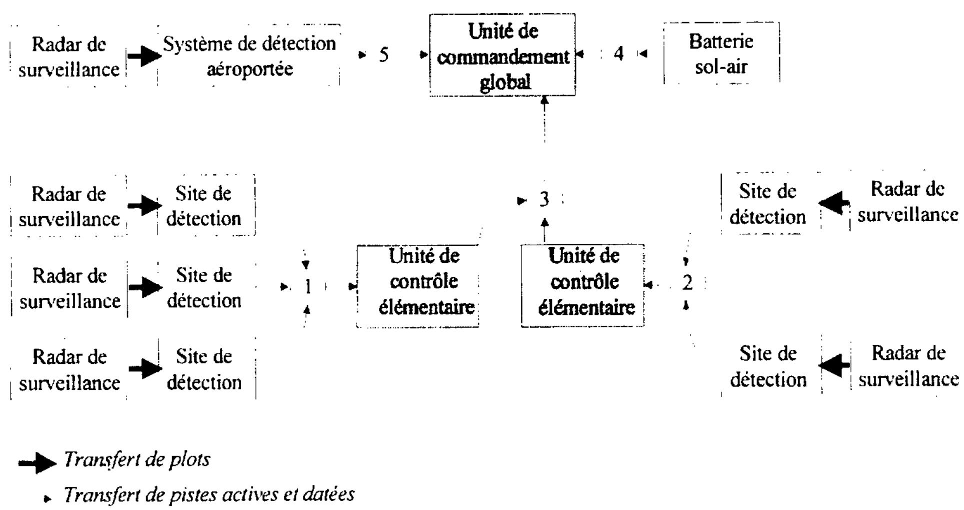
5 – 3 – Prise en compte du C3R

La « propriété » régissant les communications, ADS_DATA_LINK, intervient à différents niveaux de la défense aérienne, du bas vers le haut de la structure de la défense.

L'analyse de cette défense laisse apparaître les réseaux de communication suivants :

- D'abord, les radars de surveillance détectent une cible et créent alors un plot. Chaque radar de surveillance est relié à un site de détection, chargé de créer les pistes, à partir de plusieurs plots.
- Puis cette piste (contenant les informations décrites au paragraphe 4-2) est envoyée grâce au réseau de communication à une unité de contrôle élémentaire. Plusieurs sites de détection peuvent alimenter une seule unité de contrôle élémentaire. Une fusion de données est déjà effectuée à ce niveau. La défense est composée de plusieurs unités de contrôle élémentaire.
- Enfin, ces unités de contrôle élémentaire transmettent leurs pistes à l'unité de commandement global, qui, elle, est unique. Elle centralise toutes les informations en provenance à la fois des unités de contrôle élémentaire, mais aussi des batteries sol-air, et des systèmes de détection aéroportée. Cette unité de commandement global est chargée ensuite d'attribuer chaque cible au système d'armes le mieux placé.

Les réseaux modélisés dans cette application sont décrits dans la figure 4.



1 – 2 : réseaux de transfert des pistes entre les sites de détection et les unités de contrôle élémentaire

3 : réseau de transfert des pistes des unités de contrôle élémentaire vers l'unité de commandement global

4 : réseau de transfert des batteries vers l'unité de commandement global

5 : réseau de transfert des systèmes de détection aéroportée vers l'unité de commandement global

Figure 4 – Réseaux de l'étude

5 – 4 – Evaluations

Ces travaux ont permis d'étudier, entre autre, l'influence des retards de transmission, dans l'engagement des cibles, et d'une manière plus générale d'évaluer l'efficacité de la défense aérienne ayant une architecture très centralisée de C3R.

Cette efficacité a pu être appréciée par l'analyse de certains paramètres de sortie :

- Nombre de missiles de croisière détruits
- Nombre de missiles sol-air tirés et nombre d'intercepteurs envoyés
- Délai de réaction de la défense : délai entre première détection et décision du type d'intervention, délai entre première détection et interception.

6 - CONCLUSION

La modélisation du C3R est actuellement bien adaptée aux besoins des utilisateurs d'ESCADRE et de BABYLONE.

Elle a permis la prise en compte d'architectures de défense aérienne variées en matière de C3R (architectures hiérarchisée ou distribuée), dans lesquelles les systèmes d'armes et senseurs peuvent être totalement, partiellement ou pas du tout maillés.

Cependant, cette modélisation sera prochainement améliorée pour prendre en compte une coordination générique, utilisable dans des applications ayant des thèmes d'étude différents, et plus complexe, permettant d'attribuer une cible au système d'armes le mieux placé selon un ou des critères à définir.

Les autres évolutions dépendent essentiellement des sujets des études futures et seront adaptées au besoin exprimé.

USING COMMAND AGENTS FOR MILITARY PLANNING

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Keywords:
Automated Planning, Command Agents, Course of Action (COA), Knowledge Acquisition, VV&A.

ABSTRACT: *The main objective of the CARNEADE (Digitized Air Land Battle for Analysis, Training and Decision-making) project is to meet the various needs of the French Army and the DGA (the French acquisition directorate of the Ministry of Defense) in the following areas : Training of Headquarter staffs at Brigade level and above, Operational decision support and Force System analysis. For this main objective, the CARNEADE project consists in the development of a family of tools based on a common air-land battle simulation kernel.*
Sizing own forces and improving Courses Of Action (COA) are complex issues in the combat operations preparation. This paper presents the functional and technical approaches used in the Army Operational Planning Demonstrator (DPO) to provide staff officers with an effective framework for military planning.
The corner stone of this development is the use of Command Agents (CA) modeling the division, regiment and company commanders decision-making processes. The friendly and enemy division CA's elaborate separate Courses Of Action and those COA's are then played one after another in the combat simulation system. The simulation results are finally used by the military staff to evaluate and compare the friendly COA's.
This paper presents the various techniques used for military knowledge representations of tactics, tasks and missions at the different Army echelons. Issues related to flexibility and effectiveness of planning services are examined and then problems associated with Command Agents, such as knowledge management and VV&A, are addressed. Finally lessons learned for future developments of the program are considered..

1. Objectives and Background

The main objective of the CARNEADE (Digitized Air Land Battle for Analysis, Training and Decision-making) project is to meet the various needs of the French Army and the DGA (the French acquisition directorate of the Ministry of Defense) in the following areas: Training of Headquarter staffs at Brigade level and above, Operational decision support and Force System analysis. For these main objectives, the CARNEADE project consists in the development of a family of tools based on a common air-land battle simulation kernel.

Modeling not only covers mission performance, with real-life behavior of the units in their environment, but also the decision-making process.

Command Agents, computer components simulating the decision-making processes at the various command levels, are used whenever needed. The main advantage of using the Command Agents formalism is, in particular, that it makes it possible to reduce the staff necessary to operate the simulation and thus, reduce costs, while offering ultimate objectivity and realism.

The French Army General Staff and the DGA/SPOTI manage the CARNEADE project.
The Defense Analysis Center (CAD) and the Army General Staff-Operations Research & Simulation Center (CROSAT) are the technical & operational Advisors for the CARNEADE project. The engineering work is conducted under a consortium of five companies : AERO, THOMSON-CSF DETEXIS (formerly DASSAULT ELECTRONIQUE), GIAT INDUSTRIES, MATRA SYSTEMES & INFORMATION and SYSECA .
At present, this project has led to the realization of three operational demonstrators that testify to the technical feasibility of the system's innovative concepts.
The first demonstrator consists of three simulation tools : force tailoring tool, tactical tutoring tool and decision-making support tool. It has been realized in 1993 and it simulated in a fully automated way 36 hours of battle in two hours : a friend armored division leading delaying maneuver. It is based on a common simulation kernel. The purpose is to demonstrate the capability to meet various requirements with minimum specific adaptations.

The second demonstrator is a " Forces overseas " tactical tutoring tool for a group of three officer players. Its main objective is to prove that the common simulation Kernel could easily evolve in order to take into account new theaters and terrains (of desert type), new military actors (light forces), and new doctrines (friend attack). Enemy combined Arms Task Forces are conducted by Command Agents, only an officer animator controls their actions.

The third and the last demonstrator of the feasibility phase, the **Operational Planning Demonstrator** (DPO), has two main objectives:

- determine what is the efficiency of functions and services for an operational planning tool,
- improve CAs techniques.

This demonstrator is developed within the framework of a changing geostrategic concept. It is a peacetime/crisis operational planning tool. It is meant to show the capability of the common simulation kernel to tackle modular force compositions and changing doctrines. It determines the best force for a military engagement both in term of volume and type that directly impact on the success or failure of the force performing the mission. Such a tool enables to optimize the composition and the courses of action of a French division/brigade force (of about 10 000 combatants) that is engaged in a given theater against a given threat, in an offensive action of area reconquest.

2. Structure

The existing hierarchical structure of the French military forces with Orders, Reports through this structure is represented as such in the simulation.

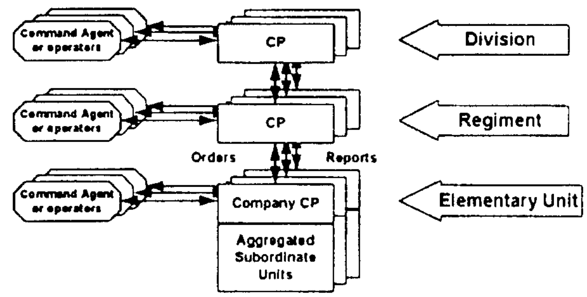

Figure 2.1 : modeling of hierarchical structure of military forces

The High level is a French Division and elementary units represented by aggregated models are at company/squadron level.

At each level of Command, a **Command Entity** (CE) is modeled through :

- **Command Post** (CP) Platform behavior that represent physically the CE, modeling its movements, destruction's..... Since Command officers operate from vehicles on the battlefield the Command Entity must also be associated with simulated vehicles. Some communication services are also associated, including access to descriptions of the communication networks assigned to this unit, and management of a queue of incoming messages.
- **Command agents** (CA) that simulate the CP officers decision-making processes during the battle, taking part into the perception-decision-action cycle. The perceived battle situation by each unit is transmitted by reports to the upper level and orders are sent to the subordinate units by means of operational messages.

At the lowest level, elementary units are represented by command entities associated with physical activities models that simulate physical behaviors of subordinate units. These models are aggregated and represent for

example: infantry companies, tank squadrons, engineer sections...

More than 100 CE are modeled in the simulation subsystem of the DPO without any operator in the loop.

3. The DPO Planning Process

The planning process of the DPO begins with the definition of an initial operation context :

- the enemy (volume and mission),
- the environmental conditions (terrain, weather conditions, presence of civilians,..),
- the mission given to the friendly forces,
- a global volume of the friendly forces (global description and maximum number of the different types of friendly units),
- a set of constraints to be satisfied (no side effects, allied and joint coordination, specific initial instructions.....).

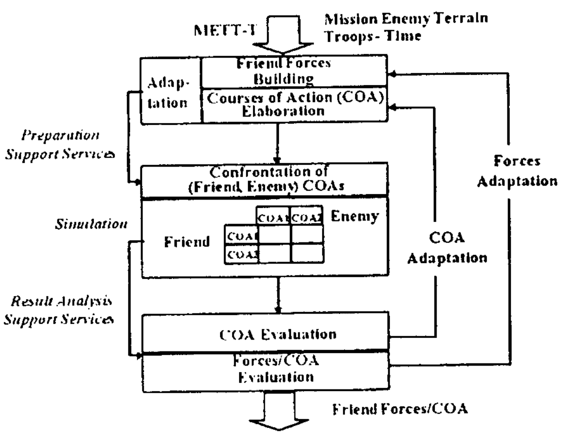

Figure 3.1 : description of the planning process

The operator of the planning tool then chooses :

- a composition of the friendly forces from the global volume, under certain constraints,
- a set of friend and enemy courses of action amongst those elaborated and proposed by the tool,
- a set of indicators that will be used to assess the different friendly courses of action.

The simulation tool then enables the assessment of the various couples (friendly forces composition, friendly courses of action) against the various enemy courses of action, and rank those couples by exploiting the simulation results (looking at the values taken by the indicators).

From the simulation results, the operator can then :

- adapt a friendly course of action,
- modify the friendly forces composition,
- relax some constraints,
- and then go back to the simulation.

In this planning process, Command agents at all levels of forces apply the unique principle of the French MRT (Tactical Reasoning Method).:

The process for choosing the best course of action, is a progressive approach by different analyses : context (METT-T...), structure of maneuver, satisfaction of constraints, quantified the different structures of maneuver for the mission by a fuzzy logic evaluation process.

4. Technical Description

4.1 Command Agents common architecture

The architecture of Command Agents is based on two concepts : a **monitor**, and a library of **base functions**. The monitor manages the internal state of the agent and sequences the elementary functions according to a state-transition-action graph (very similar to a finite state machine formalism). The base functions fall into two classes :

- **Operational functions** (or knowledge-based functions) model the CP operational activities at CP or cell level. These functions enable :
  - tactical situation assessment and update
  - maneuver elaboration
  - maneuver planning
  - maneuver control
- **Service functions** implement the management and execution of technical tasks such as data collection, tactical situation management, message management and processing, scheduling, communication services, etc.).

At each level, the relative weight of operational and service functions and their complexity depend on the nature of the processes and actions modeled. In particular, tactical knowledge and courses of action elaboration is more complex at division level than at regiment level. This explains why different techniques have been used to model tactical knowledge at the

different levels. Organizing and formalizing this knowledge is a key factor for the success of such an enterprise as CARNEADE. This explains why a significant amount of effort has been devoted to knowledge acquisition, engineers and officers working in close collaboration throughout the process.

4.2 Major Units (Division / Brigade) Command Agents

The initial maneuver elaboration is based on the maneuver margin concept and a constraint-based reasoning mechanism. The Maneuver margin describes the set of actions selected to fulfill the assigned mission. During the elaboration process, the maneuver margin is constrained by various analyses concerning eligibility of actions with respect to tactical situations, mission phases, etc. A fuzzy-set based formalism is used to represent the imprecise knowledge used during these analyses. The process finally ends up with a reduced margin which only encompasses the eligible courses of action.

Based on the reduced margin, final course of action elaboration consists in fixing the implementation details for the selected actions: location and time, type of units employed, etc. The following phases are:

- **maneuver planning**, based on a joint forces deployment plan complemented with specific plans
- **maneuver control** and plan adaptation.

The overall maneuver elaboration, planning and control process at the Division/Brigade level is based on the use of a **hierarchy of expert rules**, which provides a maximum flexibility in terms of use and representation of knowledge.

4.3 Regiment level Command Agents

At the regiment level, knowledge representation is based on the use of **decision tables**. Decision tables are used at two stages : maneuver initial elaboration, and maneuver control.
Once a new operations order is received from the upper level, decision tables are used to determine the best course of action according to a factor analysis including mission nature, terrain, means and enemy situation. Maneuver control decision tables are triggered upon message reception such as subordinate units reports, upper level orders or occurring events (end of fire...).

The readability of decision tables is a key advantage for knowledge acquisition. They are usually complemented with planning algorithms used to represent the behavior of supporting units, artillery and engineers.

4.4 Elementary Unit Command Agents

In CARNEADE, elementary units are **aggregated models** that represent companies, squadrons, engineers sections, etc. The goal of aggregation is to limit the number of parameters required to describe these complex structures, and consequently :

- facilitate physical activities modeling
- enable their monitoring via a finite state machine
- reduce computation time
- reduce the amount of descriptive data.

Very similarly to what has been described above for Command Posts, elementary units are decomposed in terms of **decisional** and **physical** behavior. The main difference is that the lower levels are not explicitly represented in the simulation. Therefore :

- the information sent by the execution part of an elementary unit to the decision part of the model are a synthesis of the data that would really be transmitted
- the " orders " sent by the decision part of the model are different from real orders, and in fact very close to an **action intent**.

Tactical knowledge used at this level is represented by means of **Mission Graphs** which define for each mission type the list of successive actions and states, with associated transition conditions.
Finally, **physical behavior** at the elementary unit level is represented through action models such as move, observe, fire, ... interaction and reaction models.

4.5. The terrain in the DPO

In the DPO, the physical models act on a physical representation of the terrain, as in any simulation. This model is not satisfactory for the CAs because of two reasons:

- CAs, like the commanders, don't think about altitudes, segments of road... but about crests, routes...
- changes in the physical terrain (e.g. a bridge is destroyed) are not immediately known by the commanders but after an acquisition process.

In order to take those remarks into account, a specific model of terrain is used by the CAs. It is called the Decisional Terrain (DT). Each CA reasons on its own instance of the DT. The following figure shows the generation and use of this terrain.

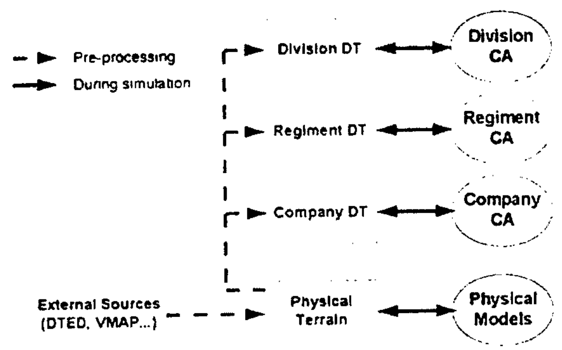

Figure 4.5.1. Terrain models generation and use

For consistency purposes, underlined in the following paragraph, the DT is generated from the physical terrain. The DT is partly pre-processed before the simulation because of performance issues: crests or forest borders extraction... Then during the simulation the CAs use these elements to elaborate directly usable features like maneuver lines, routes...

5. Knowledge acquisition and management

One of the major challenges of the project has been knowledge engineering and especially the answers to two questions: (1) How to make sure that the final product is valid ? (2) How to manage a large amount of knowledge efficiently ?

5.1 The lessons learned from the previous demonstrators

The lessons drawn from previous developments helped us a lot for defining a methodology and for developing tools to support knowledge engineering in the DPO project. In order to understand this background and the reasons which led us to some choices, this paragraph sums up the most important difficulties, related to the CA, we encountered during those preliminary experiences and the various sources of mistake we discovered when validating the simulations.

The most common error is a lack of understanding between two CAs: a CA sends a message to a subordinate CA which doesn't react as expected by the first. In order to understand the sources of this type of error, the figure 5.1.1 presents a synthetic scheme of the knowledge acquisition and modeling process.

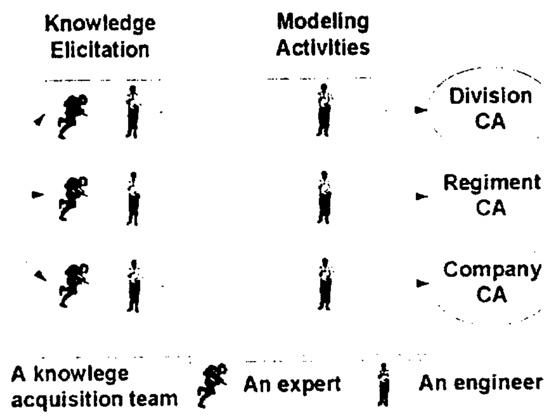

Figure 5.1.1. Acquisition and modeling process

Some problems came from the knowledge elicitation phase where two typical errors have been made:

- in spite of multi-level discussions, during which experts and engineers gathered to decide how to conduct some missions and especially what messages (orders) would be exchanged, some choices were made afterwards separately by the **knowledge acquisition teams** (KATs). These choices led to divergences from the initial meaning of the commonly defined messages (even if the formats were unchanged) and later led to some integration "disagreements".
- the other error is well-known in knowledge engineering: the engineer understanding of what the expert says is not exactly what the expert meant.

During the modeling phase, some new approximations were made by the engineers and they also led to divergences between the CAs.

Those mistakes can be considered as typical knowledge engineering errors. Some others follow which are out of this scope and relative to data:

- parameters used in the physical world differed from those used in the CAs. It led to errors like, for example: a company CA starts firing with a non-optimal distance of engagement, but "thinking" it is. As learning is not integrated in our system, the unit has never correctly engaged combats. So it is necessary to have a direct relation between the physical characteristics of the weapon systems and the CA's knowledge.
- terrain representations were not consistent. This leads to errors like: a tank CA commands its

subordinate CAs to drive through a plain but its subordinates see a forest in their decisional terrains. They consider their mission is not feasible, their commander considers it is and they enter a dead lock. The same error can occur between a CA's decisional terrain and the physical terrain.

The reader can notice that those last issues are parallel to those encountered within simulation federations.

In the validation phase, discovering the origins of such misbehaviors has sometimes been very expensive. For instance, the effects of a division CA mistake were sometimes visible only a few hours after the erroneous decision was taken. Furthermore, discovering the origin of the mistake can take a few days. For this reason, in order to avoid the errors listed above, a knowledge elicitation and validation methodology and associated tools were developed in view of:

- developing semantic interoperability between the knowledge acquisition teams,
- reducing the "mental distance" between the expert and the model.

5.2 The knowledge elicitation process

The knowledge acquisition and modeling process used within the DPO is shown on figure 5.2.1.

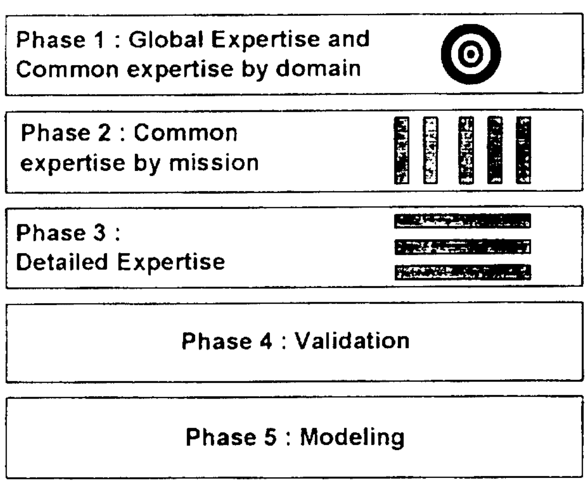

Figure 5.2.1. The knowledge elicitation process

The whole acquisition and modeling team is present in common meetings during phase 1 (experts and engineers in charge of decision modeling and of physical world modeling). They agree on a common modeling framework related to the division types of mission which can be played (relevant Courses of Action, limits of the environmental conditions...). Then a more detailed analysis is conducted for each military domain (e.g. artillery, intelligence...): context of use of the units and of their capabilities, phenomenons to be represented, coordination with the other domains... The presence of the people in charge of the physical world modeling is decisive: they insure the CA decision effects will be adequately represented and conversely the CA can react to the physical world events.

Phase 2 continues with the same teams in common meetings. However, the physical world modeling engineers participate only if required. Here, the basic elements of analysis are the missions: either missions assigned to the regiments by the division or to the companies by the regiments. The context of each mission is discussed: what is expected by the superior, what the subordinate expects to do, what information is needed in the message in which the mission assignment is formulated, what information is exchanged during the mission...

Phase 3 is dedicated to a fairly detailed knowledge acquisition. Starting from the parameters describing the operational external context of the missions, each team has to define, at the concerned level, the mission execution characteristics. When external parameters depending on two (or three) levels have to be changed, a new multi-KAT joint meeting is necessary.

Phase 4 is part of the validation process: each domain expertise is presented to independent experts of the domain. The expertise is validated considering the results of each team. This guarantees an inter-level consistency based on both the control of the independent validation team and the care taken by the acquisition team to present its work.

Finally, phase 5 is the modeling phase where knowledge is represented with the adapted formalism. A tool, presented in paragraph 5.4, has been used for the company level CAs.

5.3 Validation

The validation activity comprises two major stages:

- the first one, as described in paragraph 5.2., whose objective is to validate the expertise. The opinion of an expert is confronted to an independent team of experts. Most of them were teaching in military academies or had been assigned to doctrine centers.

- the second stage objective is to validate the software. It is conducted in reverse order of the knowledge acquisition. (1) in each CA, an elementary validation insures that each mission can take place as specified in phase 3 of the acquisition (detailed expertise). The experts can experiment the application of their knowledge modeling on some real (simulated) cases. Except for some minor mistakes, the average behavior of the CAs was correct but the experts often discovered some lacks in degraded cases (e.g. a unit deprived of a part of its subordinates). At the end of this first phase, the CAs have a correct individual behavior. (2) The global validation is then conducted, first by validating each military domain representation (for this, part of the division CA can be used separately) then finally with the whole software. This activity takes a long time because of numerous external conditions to test: forces composition, weather, terrains...

5.4 Tools

Some tools were developed for helping the developers of the DPO. Two of them were especially helpful:

- **the GMT editor**. This tool is an editing support for the company level knowledge modeling. This tool is user friendly and both the engineers and the experts working on this level of command used it. The benefits drawn from it is that it provided the "company KAT" with a formalism and a tool allowing them to discuss and finally to agree on a unique and definitive representation of the expert knowledge (because directly used by the software). That is what we previously called a "mental distance" reduction.
- **the testing tool**. In order to test the CAs individually, we had to generate a lot of external stimulations corresponding to the orders or reports exchanged with their environment in the simulation. Those messages were generated by a testing tool designed for simplifying the messages fields filling. This tool was based on a messages format repository which permitted to follow the formats evolution in a transparent way. This repository was used too to automatically generate the pieces of CA software relative to common types and to messages encoding/decoding.

6. Lessons learned

6.1 User Acceptance

Although the use of command agents offers unquestionable advantages such as staff reduction and games reproducibility, it requires important efforts in terms of knowledge acquisition and formalization, and validation. The results must be indisputable, which means that users must have a total confidence in the simulation tool. In order to achieve this, it appears that the following conditions must be met :

- Officers implied in the expertise acquisition process must be in activity and aware of the last doctrine evolutions in order to give an official recognition to the models
- Physical data used in the models and their simplifications must also be collected through and approved by operational officers
- Both physical data and knowledge must be accessible to users in an intelligible form , along with a clear indication of their origin (for certification purposes)
- Traceability is a key success factor : providing the user with the trace of the reasoning facilitates his understanding of the process and his confidence in the simulation tool ; traces also facilitate the validation process and help the user to intervene in the simulation process in an appropriate manner.
- Man in the loop and decision automation must be combined in an harmonious way to provide the most effective compromise between the realism of a human-driven game and the effectiveness of the simulation.

6.2 Technology Assessment

In the context of the Operational Planning Demonstrator (DPO) development, various techniques have been used to implement Command Agents according to the hierarchical level. Overall, these techniques proved to be relevant, each of them with advantages and drawbacks, especially with respect to the officers' ability to understand and master the underlying modeling paradigms. For example, the fuzzy rules based technique used at division/brigade level enables unprecise knowledge formalization but is more difficult to apprehend than the decision tables or mission graphs technique.

Finally, the lowest aggregation level selected has been in general the company level, but experience has shown that this level could vary according to the type of maneuver, and also according to the type of force (esp. for support forces).

Author Biographies

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Martine MICHEL is Project Manager in the simulation department of SYSECA, a software and services subsidiary of Thomson-CSF, France. She has been working for 6 years on the CARNEADE project and also on various related fields (tactical trainers, data fusion systems...)

Integrating Operational and Systems Architectures: How Modeling and Simulation Can Empower Command and Control Acquisition

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Both users and developers in the Air Force command and control (C^2) community believe that the only way to improve C^2 is to acquire and manage it as an integrated weapon system. Building components and hoping the end-user will lash them together correctly is a guarantee for disaster—that is not how we procure and deliver F-22s or M-1A1s. The immediate question about an integrated C^2 weapon system is how do we do it? How do we even visualize a single system composed of hundreds or thousands of human beings and workstations and possibly stretching across multiple time zones, out into space and down into the cockpit and foxhole? How do we know the best approaches to improve our operational performance across the spectrum of military operations without this visualization? How do we know the best way to integrate technological innovation into our command and control capabilities? How can we trade different proposals to improve our performance in any meaningful or quantifiable way? The answers depend on perceiving a C^2 architecture in at least three complementary ways, and in using processes and modeling and simulation (M&S) tools to integrate these perceptions and the different communities that create and use them.

For too long, the acquisition community has built C^2 capabilities as if they were end-items. The end result of such behavior is the example in December 1994 when NATO decided to create a Combined Air Operations Center in Vicenza, Italy to manage the air campaign over Bosnia. The US Air Force, as part of a NATO multi-force effort, promptly shipped tons of equipment to Vicenza. The NATO operators on site then faced a problem roughly analogous to what a fighter squadron would face if it received boxes and boxes of F-16 components and had to build its complement of aircraft then and there.

The analogy of a C^2 system to an F-16 bears up under further scrutiny: An F-16 is composed of thousands of components and subsystems, many of which are built in different locations by different vendors. These components may never come into contact until the assembly line, but they are expected to mesh together and interoperate as a single integrated system within narrow tolerances and without fault. Likewise, the acquisition community and industry will continue to build C^2 components individually, but they must adopt practices that ensure that these components are integrable and interoperable when combined into the single weapon system.

This is old ground that others have plowed and replowed thoroughly. The solution to the problem of interoperability that the United States Department of Defense has adopted is to build components in compliance with the Joint Technical Architecture, or JTA, and in compliance with a particular instantiation of the JTA called the Defense Information Infrastructure—Common Operating Environment, or DII-COE. Capabilities so built

should be able to reside on the same workstation as other capabilities, share data and use common tools and services. The ultimate goal is for capabilities currently residing on separate workstations to eventually evolve into icons and applications residing on the same or compatible workstations.

Given that the Air Force is building all of its C^2 equipment in compliance with the JTA and DII-COE, have we thereby solved all of our problems? No, because building completely modular components without a blueprint will not guarantee that putting all the modules together will produce anything in particular, e.g., an airplane that will fly or a rocket that will launch. A technical architecture is just one way of looking at an integrated system, and is by itself insufficient to characterize that system. At least two more architectural views exist, the systems architecture and the operational architecture. The Office of the Assistant Secretary of Defense for Command, Control, Communications and Intelligence (OASD/C3I) released version 2.0 of the C4ISR Common Architecture Framework, which defines these three aspects of a command and control architecture and their interrelationships. Having introduced the technical architecture above, we shall discuss the other two in turn.

Operational Architecture

An operational C^2 architecture is a description of actors, actions, processes, decisions and information. It defines the decision-makers, where they stand, what information they need with what timeliness, the range of decisions they may make, and what actors, echelons and units must receive those decisions and implement them. When the Air Force's Air Combat Command (ACC) used IDEF0 process models to capture the operations of an air operations center (AOC), they were documenting the operational architecture of an AOC. These models characterized inputs, outputs, resources and controls. They described the operations and processes necessary to generate an air task order (ATO) and to manage its execution.

A number of problems surfaced with the IDEF0 models thus developed. For one thing, production was a resource-intensive effort, calling for hard intellectual work among a number of subject matter experts. Further, they were static, and therefore captured the concept of AOC operations at the time (circa 1994-95). The slightest real-world change to operational practice, procedure or doctrine required significant rework to the model. Finally, the models were not simulations, that is, they were documentation as opposed to interactive tools. There was not a simple method available to leverage them to describe the desired state of a future operational capability. As a result, the trade of effort for result was not favorable.

Currently, operational architecures are under-documented. The USAF major commands (MAJCOMs) are beginning efforts to document their operational architectures. As they begin, the Air and Space Command and Control Agency is seeking to pull these efforts into a USAF-wide assault on the problem using common tools and processes. However, these tools and processes have yet to be refined and agreed on.

System Architecture

A system architecture is the third visualization of a command and control architecture. It describes the hardware, software and communications that support and empower warfighters in conducting C^2 operations. The current systems architecture for air combat operations contains a number of C^2 capabilities, such as the Contingency Theater Air Planning System (CTAPS), the Wing Command and Control System (WCCS) and the Combined Intelligence System (CIS). It includes as well the communications necessary to disseminate data among these systems and out to other facilities.

The C^2 acquisition community generally documents its system architectures just as incompletely. Up until the Expeditionary Force Experiment and the Command and Control Training and Innovation Center (C2TIC) initiative to baseline Air Operations Centers (AOC), the author is not aware of any serious attempts to baseline the integrated C^2 system from end to end. More often, an individual program responsible for a single capability documents the requirements for that capability alone. The program uses requirements analysis to derive systems requirements from Operational Requirements Documents (ORD). As with most traditional dialogue between users and developers, the documented results—ORDs and specifications—do not clearly correlate to each other. The need exists rather plainly for several enhancements to our current business practices:

- The operational community should incorporate end-to-end operational architecture visualizations in its requirements process, e.g., a Capstone Requirements Document (CRD)
- The development community should baseline and document existing end-to-end systems architectures to specify the point of departure for efforts to reach the objective operational architecture
- Both the operational and development communities should be able to merge their architecture visualizations so that a clear and unambiguous link exists between operator needs and proposed system solutions

Integrating the Operational and Systems Architectures

In short, the operational architecture is the C^2 user's description of what C^2 operations need to be performed and how. The systems architecture is the C^2 developer's description of what systems will be built and how they will be linked to empower the user's C^2 activities. This bespeaks the perennial miscommunication between requirements and products: They're different terms expressing different frames of reference to describe the same concept. Correlating them is beset with inefficiencies and poor translations. The user knows what he needs, and the developer builds a set of modular components that he hopes will support the necessary operations once they're built and hooked up together.

Therefore, it is necessary to integrate these architectures and to do so as early in the system acquisition process as possible. Without early and constant work, the end result has been, is and will continue to be a collection of modular systems that meet some of the users' needs but not all. Operations suffer, and the warfighters adjust their operations to

derive a set of operational processes that the systems can support. In other words, hard use in the field tends to integrate the operations and systems into a set of processes that neither the operator or user initially envisioned. Whether the new processes actually meet user requirements can be as much a matter of chance as of design.

MITRE Bedford and the Electronic Systems Center's (ESC) Modeling, Simulation and Training Product Area Directorate (MST PAD) are developing a set of tools and processes that integrate the systems and operational architectures throughout the development process, starting from the first phase of concept development. The end goal of this effort is a toolkit that the warfighting customer uses to document the objective operational architecture; that the developer uses to baseline the systems architecture; and that industry uses to propose modifications or new capabilities that evolve the as-is to the to-be. As these tools are simulations vice static models, they also offer both government and industry a powerful capability to assess the performance of these proposals.

The tools are based on Colored Petri Nets (CPN), a process modeling technique. This effort added a major refinement to Petri Nets, such that the tool user can identify and track individual processes, e.g., a loop from an operator's request for information to the delivery of information back to him. This refinement assigns a unique color to each such loop. Coloring individual process loops affords the analyst a powerful visual tool for assessing process flow through a system or system of systems. The power of colored loops has been demonstrated in a number of program design and test efforts: most notably, a message switching system that incurred problems in its initial installation

Figure 1 shows an RDD-100 model of a software communications switching system that was used to design and build the system. However, initial installation testing revealed that under certain loading conditions, end-to-end message latency was about 40 times slower than the requirement.

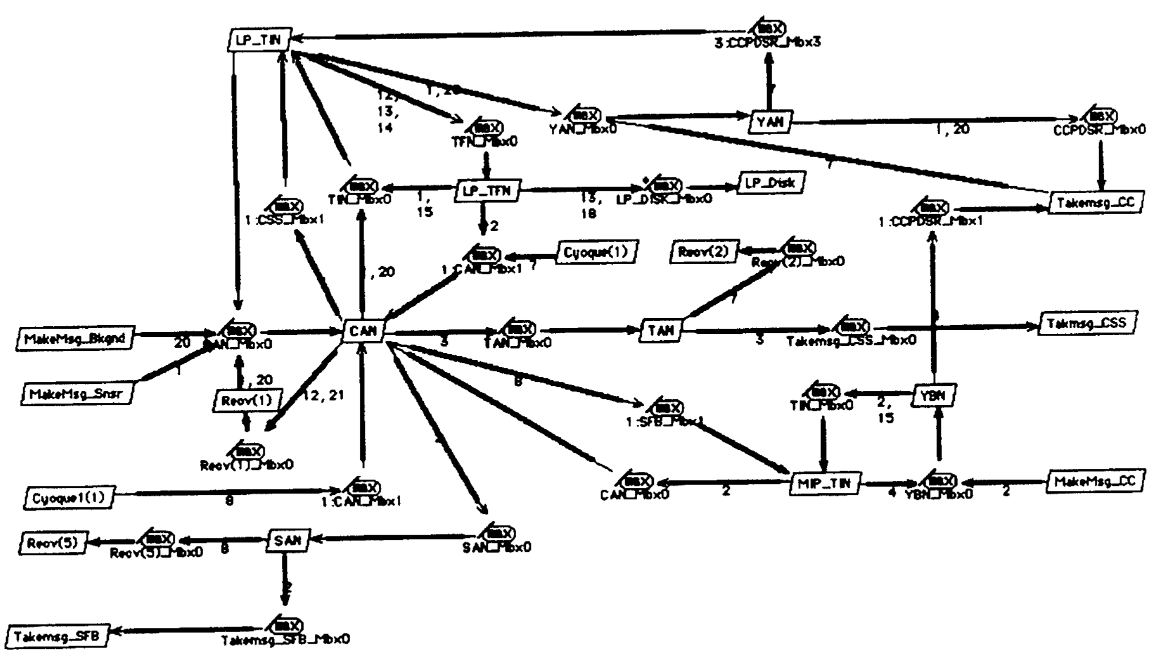

Figure 1. RDD-100 model of communications switching system

Creation of a CPN model of the system (figure 2) allowed quick identification of two nodes that every process had to flow through, often simultaneously. Simulation of the switching system correctly pointed to one of these nodes as the culprit inducing the unacceptable latency. Unfortunately, the node had not been sized to accept such a flow of message traffic, and redesign and rework induced significant additional cost. Use of this CPN technology might have allowed this development effort to avoid $10 M in cost growth.

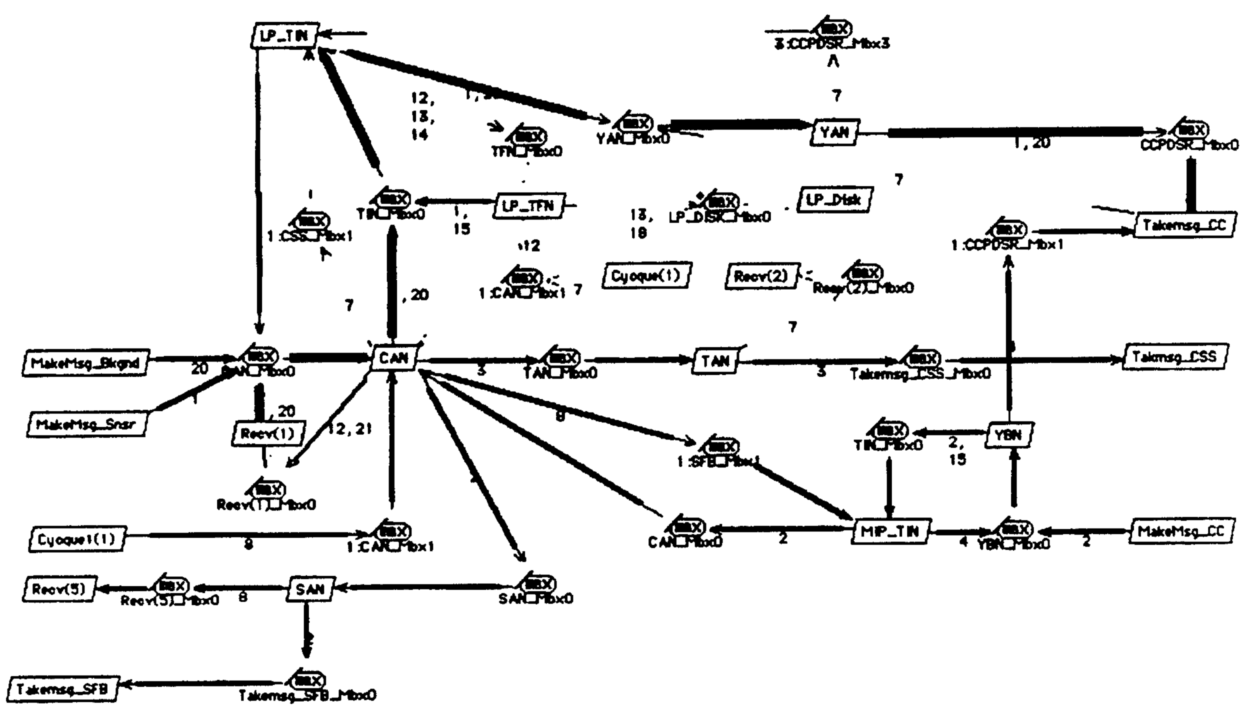

Figure 2. CPN model of the communications switching system

It is necessary to mention some other features of this process and toolkit: That the CPN tools allow simulation of the C^2 processes, that compatibility of data from other process modeling tools is fairly straightforward, and that the process is recursive. First, CPN allows simulation of processes. Simulation of any modeled process or system requires either actual system code or performance measurements. As in the above case of the switching system, both measurements and code were available, and the troubleshooting team was able to determine the size of the redesigned node in terms of data throughput in a straightforward fashion. Second, the data structures for these CPN tools have been set up such that accessing databases from computer-aided software engineering (CASE) tools such as STATEMATE, RDD-100, or IDEF is relatively easy. We obtained ACCESS databases of air operations center (AOC) processes which Air Combat Command (ACC) developed using IDEF-0. Conducting the interviews and

documentation took ACC over nine months and a large amount of resources. Converting the ACCESS databases and uploading these data into our CPN models took two weeks.

Finally, the hierarchical nature of these tools and processes lend themselves to modeling systems of systems as well as individual components. A team of MITRE, government and contractor personnel converted the AOC process models into CPN simulations of the various operational threads that comprise development and execution of an air tasking order (ATO). The result is a display of a portion of the combat air forces' operational architecture that is user-friendly (see figure 3). In contrast, the original IDEF-0 models were static representations that resembled plates of spaghetti. While necessary and valuable, the outputs of the IDEF effort were difficult to interpret, e.g., in tracing the issuance of a warning order from the National Command Authority through the Joint Force Commander and out to the wings and squadrons. In contrast, the CPN displays make it easy to follow individual processes, and to show how different processes interact and affect each other. In short, CPN modeling and simulation allows the C^2 user to document his operational architecture in a simple, comprehensible form.

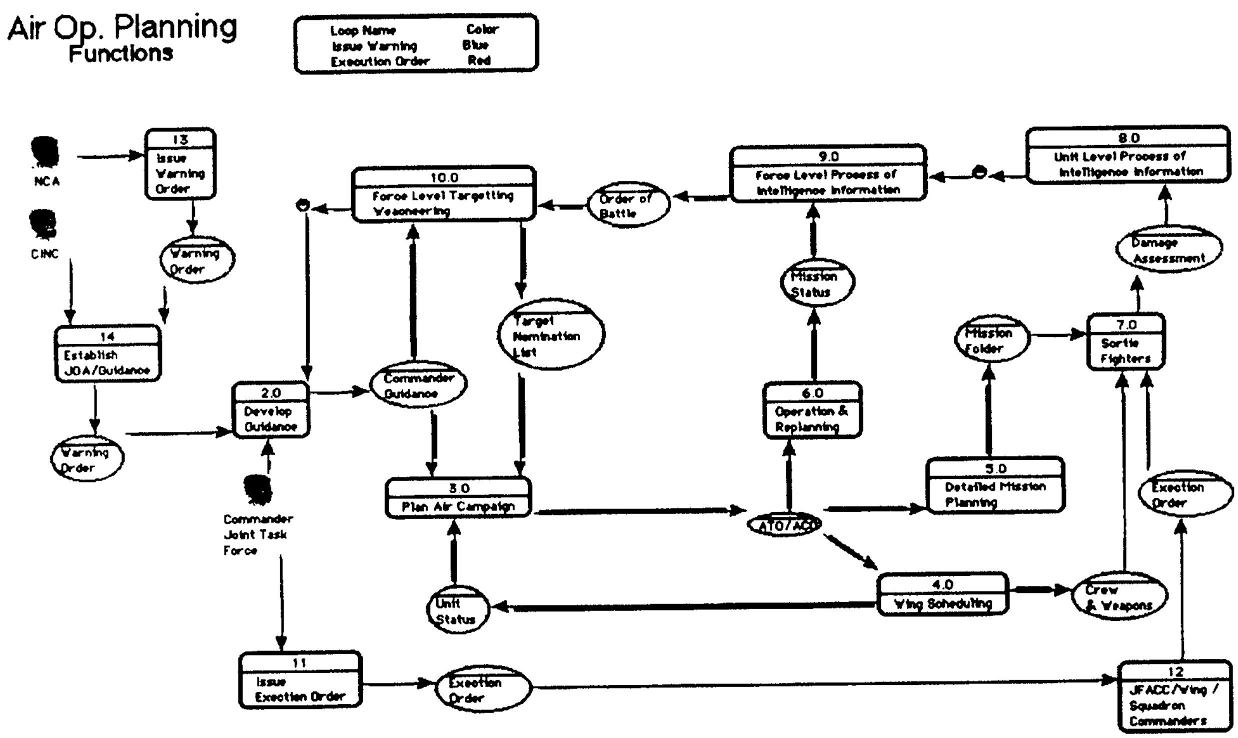

Figure 3. Air operations planning and execution processes.

In a similar fashion, the C^2 developer can baseline the system architecture and measure how closely it meets the user's objectives. A critical feature of CPN is that it allows developers to insert models of individual capabilities of the integrated C^2 weapon system directly into such an operational architecture (see figure 4). Using a compatible reverse engineering tool, the analyst or developer can create a CPN executable model of such components as CTAPS directly from their source code. The developer can integrate and simulate a portion of the operational and system architectures, limited only by the availability of data. Given an operational architecture of an AOC, he can populate that

AOC model with detailed models of the systems within it. Simulating these models then empowers performance analysis of the baseline systems to meet operational requirements.

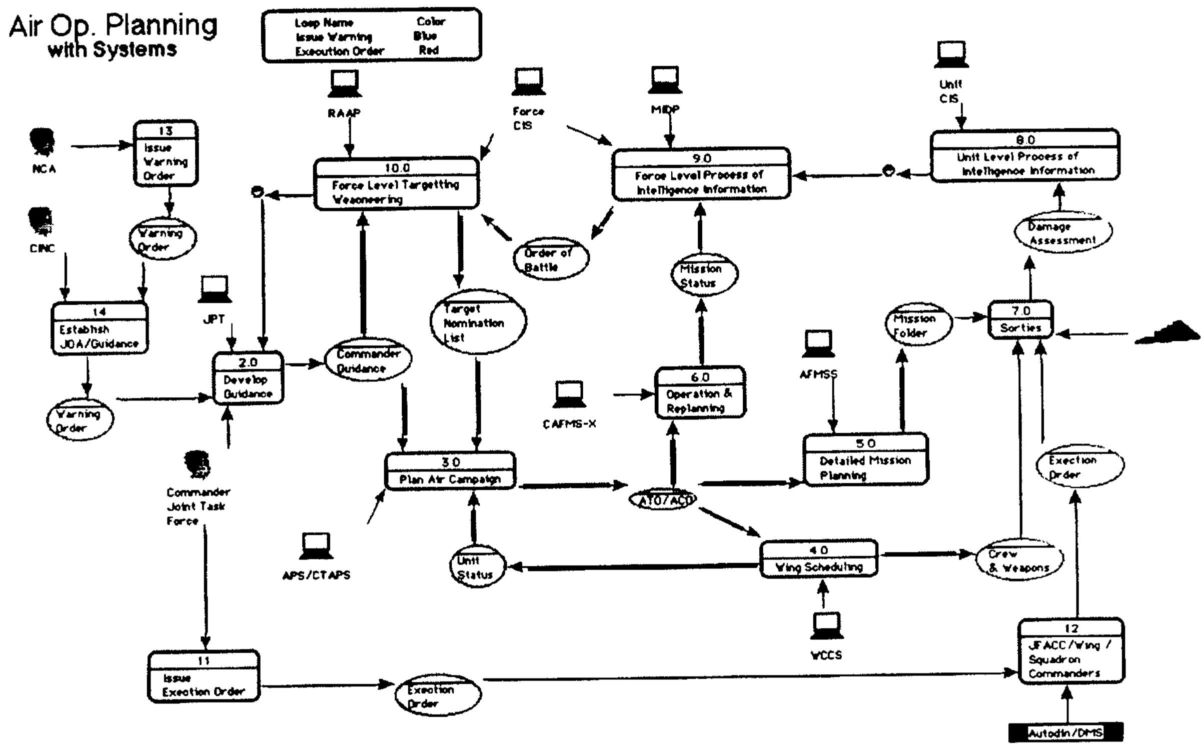

Figure 4. Integrated operations and system views of air planning and execution.

Once this baselining and documentation process is well underway, both users and developers can use these processes and tools to integrate industry into the evolution of the integrated C^2 weapon system. Making these tools available to industry is necessary, but a complementary approach would be to publish the data formats of the visualization tools and ask industry to furnish proposals with conceptual system architectures or threads in those formats. Government could then conduct performance analyses of the proposals and assess how well the proposed new capabilities integrate with the baseline systems and how well they help migrate the baseline to meet user requirements.

Summary

The command and control user and developer communities are wracked by the same difficult communications that beset any community speaking requirements versus specifications. This problem complicates the larger issue of trying to create and manage C^2 as an integrated weapon system. The Model Reference Technology is an evolving process and toolkit that can help these communities document their different frames of reference of a C^2 architecture, merge those operational and systems views into a single recursive representation, and discuss and assess various approaches to improving the integrated C^2 system with industry. These processes and tools have proven their worth in

isolated cases, and need to evolve further. Finally, the larger community of government and industry must use these tools and processes and incorporate them into the way they do business.

Modeling Decision Expertise for C^2 Analyses

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1 Description of the problem

Human decision making is central to command and control, and decision quality can significantly impact C^2 effectiveness and the achievement of military objectives. Unfortunately, however, the immaturity of decision making models (Pew, 1998) impedes studies in which decision quality is an important factor affecting C^2 and mission effectiveness.

This paper outlines a methodology for modeling decision quality and timeliness within C^2 simulations. It estimates the correctness and timeliness of decisions given the quality of the decision maker's situation picture and his level of expertise, as modified by performance factors such as stress and fatigue, by experience, and by decision support systems. The models employed in this methodology are based on cognitive theories of expertise (Chi, 1981, Noble, 1993, Deutch, 1992).

This methodology focuses on contingent decision problems in which the decision maker must choose between previously specified alternatives, where policy and doctrine for making the choice are clear, but where the applicability of the policy to the current situation may be obscure. That is, the alternative that should be selected is clear if the situation can be understood correctly, but this understanding may be very difficult. We are not modeling the more complex decision making requiring planning and identification of alternatives.

Figure 1 summarizes the key factors addressed by the model. The model estimates decision quality given the difficulty of interpreting the situation correctly and decision maker "effective" expertise. Difficulty of interpreting the situation depends on the quality of the situation picture (accuracy, completeness, precision) and on the familiarity of the situation. Effective expertise reflects the decision maker's innate expertise (experience, level of skill), modifying soft factors such as stress, time pressure, and fatigue, and decision and situation assessment support tools, such as expert systems able to increase the effective level of decision making expertise.

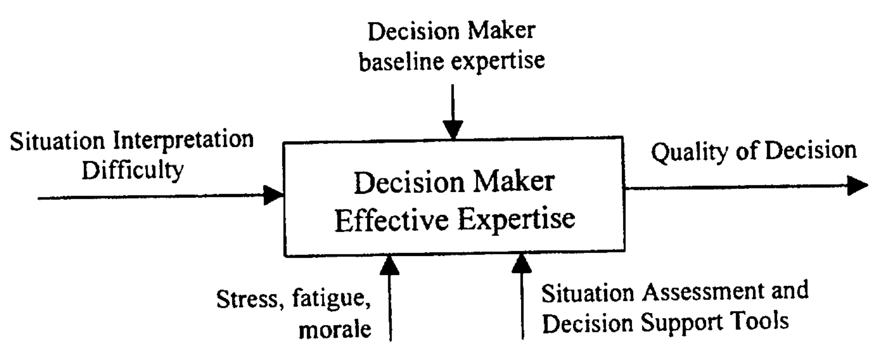

Figure 1. Key factors Impacting Quality of Decision

Benefits. The proposed model framework, when applied as prescribed by the Code of Best Practices, will enable automated simulations to address important C^2 issues that today can be addressed only by more expensive "man-in-the-loop" simulations. They will help clarify the impact on the quality and timeliness of decisions from such factors as:

1. The quality of the situation picture. The quality of the situation picture is its completeness, accuracy, precision, currency, and lack of clutter. Quality depends on the timeliness, precision, and accuracy of the sensor data and other situation reports, on the effectiveness of fusion and analyses processes, and on timely distribution and management of the picture. It also depends on adversary information operations that may degrade the quality of the picture.

2. Increased expertise and decision aids. Training, experience, and level of skill affect expertise. Situation and expert system decision aids can improve the effective level of expertise by making the expertise of more experienced decision makers widely available.

3. Fatigue, stress, time pressure and other factors that effectively reduce the level of expertise on quality and timeliness of decision making.

In addition to benefiting the studies that use these methods, this framework will also contribute to the modeling and simulation technology infrastructure. It will provide insight on methods for modeling expertise and for quantifying and characterizing situation quality and the difficulty of correctly interpreting the situation picture.

Status. Research to support these situation-based models of expertise and situation quality has continued over the past ten years (Noble, 1989). These models have been used in experimental decision support systems to help intelligence analysts recognize threat operations and to help operational commanders make time-pressured decisions under stress. The models have not, so far, been embedded within C^2 simulations.

During the next year, these models will be further evaluated during workshops sponsored by the Command and Control Research program (CCRP). Workshop participants will include decision modelers from the United States, United Kingdom, and possibly other NATO countries.

2 Modeling the Impact of Expertise

This methodology for modeling expertise is embedded within the event flow of Figure 2. Using the cognitive models described in this paper, simulated actors perceive a situation and decide what to do. Then using models of sensors and physical processes, the simulation determines the impact of the decided actions on the environment, computes a new ground truth, and estimates the possibly flawed situation picture that analysts can produce from sensor reports of the new situation.

This section describes the cognitive models used to interpret a situation and to select an action. It first describes the representation of knowledge associated with different levels of

expertise, and then discusses how people with various levels of expertise interpret a situation and decide what to do.

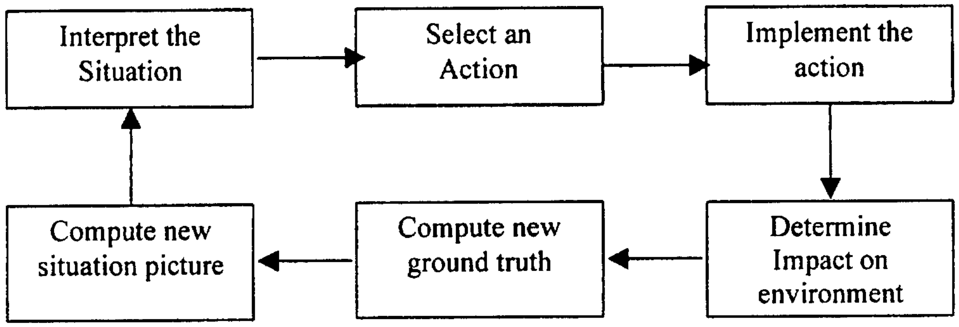

Figure 2. Event Flow for Modeling Expertise

2.1 Modeling expertise

Our models of expertise are based on cognitive theories (Chi, 1989, Klein, 1998). These models group expertise into four levels similar to those discussed in the draft CoBP. These include the routinizers, analyzers, and synthesizers in the draft CoBP. However, the more modest "meta- synthesizer" has replaced the creator level of expertise because true creators are both very rare and probably impossible to model.

Table 1 summarizes some characteristics of these four levels of expertise:

Table 1: Characteristics of Levels of Expertise.

Level of Expertise	Characteristics
Routinizer	Rule based. Applies concrete rules. Does not know cause of rules, can't weight rules, doesn't know when rules should be violated, has no way to resolve contradictions or make trade-offs.
Analyzer	As in routinizer, but has more rules which consider more aspects of the situation. Understands linkages and trade-offs for a subset of rules.
Synthesizer	Qualitatively different from lower levels. Uses general abstract rules that capture the reason for an action and specify types of situations in which rule is appropriate. Synthesizer users functional schema to classify type of situation. Synthesizer classifies an observed situation by matching properties of observed situation with properties expected from various types of situations. Classification considers properties consistent or inconsistent with expectations with each situation type, properties expected but not observed. Final classification considers match across situation types.
Meta Synthesizer	As above, but can represent situations and match situations to decision alternatives at a higher level abstraction, and can detect more subtle patterns of situation properties.

The models describe conjectured mechanisms that underlie these different levels of expertise. The first two levels of expertise, the routinizer and analyzer, are the novice and journeyman levels. Both are modeled using "bottom-up" rule bases which connect various features of a situation to a prescribed decision alternative. They differ in the completeness of the rule set. The second two levels of expertise, the synthesizer and meta-synthesizer, are expert levels. They are modeled using abstract general rules and top-down functional schema.

The knowledge structures and cognitive processes of the expert levels differ qualitatively from the novice and journeyman levels. The following example, from anti-ship self defense, illustrate these differences. In this example, policy and doctrine dictates that hostile aircraft intending to attack the ship should be destroyed before they have a chance to attack. To simplify the analysis, only the novice and expert levels (routinizer and synthesizer) are discussed.

Novice rule sets. The novice has a set of rules to be followed, which higher authority would set for each engagement. An example of such a rule would be:

IF an unknown aircraft is within 50 miles, is closing on the ship, has not responded to warnings to turn away, and is emitting a fire control radar,

THEN destroy the aircraft.

Such rules are suitable for the cases anticipated by higher authority. However, like all rule sets, they tend to be brittle, unable to handle important exceptions and special cases. In addition, if the situation picture is unclear, then the applicability of the rules can also be unclear.

Expert top-down functional schema. Like a novice, experts can determine what to do by applying rules. However, an expert can also apply much more powerful, general, and robust knowledge and analysis methods. These can work in atypical and unexpected cases where rule sets fail. They can also overcome incomplete, inaccurate, and imprecise situation pictures.

The "top-down" functional schema provide a fundamental understanding of "how the world works." The knowledge has two major parts: functional models of how the world works, and a knowledge base that maps observable physical characteristics of a situation to these functional models.

In the anti-ship example, the policy to be followed can be summarized by the general rule: "if an aircraft-intends to attack the ship and is an imminent threat, then destroy it." An expert can apply this abstract rule because he has general world knowledge about how attacks are done as viewed from the adversary's perspective of what must be accomplished to solve an "attack problem." From this perspective, aircraft with a particular behavior might be attacking if the political and military preconditions for an attack are satisfied and if the aircraft is taking the actions required for an attack to be successful.

An example of preconditions for an antiship air-to-missile attack might be:

Precondition:

Conditions are compatible with an attack. Declared conflict, facing adversary with motive, such as revenge, pride. Adversary has capability.

An example of an expert's understanding of what must be accomplished for an attack to succeed might be:

Requirements for attack to succeed:

1. Missile capable platform (military aircraft, modified civilian airliner, helicopter) must be available.
2. Platform must penetrate to missile launch zone (may come in force to overwhelm defenses, use deception, or avoid detection through stealth).
3. Platform must obtain targeting information (from cooperative targeting with helicopter or aircraft like P-3, from submarine providing targeting information, or from its own search radar)
4. Before launching missile, platform must be in position to launch (be at proper altitude, bearing, range).
5. Missile must have means to be guided to the target (fire control radar)

An expert can interpret specific situation data in terms of this functional schema, and can use the schema to interpret unusual or unfamiliar circumstances. For example, the pilot of an approaching hostile-nation aircraft might be claiming asylum and protection from the battle group. The expert commander would recognize that while this could be the case, it is also possible that this pilot might be trying to find a way to penetrate to within missile launch range of the ship. If the preconditions for an attack existed, the commander would most likely not permit the aircraft to advance within its missile launch range.

Note that this approach toward modeling expertise differs from some previous efforts. For example, in the method described in a recent comprehensive review of C2 modeling (Pew, 1998), expert versus novice differences were "generated from an adaptive planning model by varying the amounts of training that is provided a particular decision tasks." In contrast, this approach posits qualitatively different knowledge structures and reasoning structures for novices, journeymen, and experts, and represents these differences declaratively in simulation knowledge bases.

2.2 Using Expertise to Make Decisions

In the contingent decision making addressed in this paper, decision makers will select pre-planned alternatives when the conditions are right for those alternatives. Therefore, to decide what to do, they must interpret the situation to determine which of the relevant situation conditions are present, must assess the applicability of each alternative given these conditions, and then must either select an alternative, defer a decision, or decide that a new alternative is required.

Novice Situation Interpretation. In our models, experts are much better at situation interpretation than are novices. The novices interpret the situation by deciding which of their rules apply to the situation. If rules for alternative conflicting actions seem applicable, the novices weight the importance of each rule to decide on which action to

take. Novice's rules match at the physical level; e.g., all rules are expressed in terms of the identity and locations of physical entities or on the sequence of observed events.

Novices may interpret situations poorly for several reasons. First, rule sets are invariably incomplete (the "qualification" problem in artificial intelligence), and the sets used by novices are likely to be seriously incomplete. Second, a novice might not recognize that a rule is applicable if the situation is ambiguous, so that the match of situation to rule is uncertain. If he does recognize it, he might not reduce the weight of a rule properly to reflect this uncertainty. In addition, he may be unable to adjust the weight of rules that just barely match. For example, a rule may specify that a track should be traveling faster than 400 knots. A rule triggered by a track at 500 knots would not receive more weight than one triggered by a track whose speed is 401 knots. The novice will not be able to adjust these weights if he does not understand the rationale for the rule.

Expert Situation Interpretation. The expert uses much more powerful and general methods for situation interpretation than does a novice. Rather than using the narrow concrete rules of novices, the expert uses a combination of functional schema, a few general abstract rules that reflect the real reasons for taking various actions and a set of "starter" rules to trigger the assessments of applicable general rules. In situation assessment, the expert:

1. Notes the match of the situation to the "starter" rules for possible multiple competing general rules and identifies the general rules that might be applicable, given the match on the starter rules.

2. Generates a set of expectations should each of these general rules be applicable. For example, the general rule triggered by a pilot approaching a ship asking for asylum might be "destroy an aircraft intending to attack the ship." The expectations are other elements of the situation that should, or should not be, present should this rule be applicable.

3. Checks the situation to see which of these expectations are met or violated.

4. Compares each of the general rules, determining the balance of expectations met or violated for each of the general rules.

Experts avoid many of the pitfalls of novices. Their effective concrete rule set, organized in terms of the more general and robust abstract rule sets, is much larger. Like novices, experts still have a "qualification" problem, but the problem arises less frequently. Experts can handle uncertainty better, because they consider the aggregate of all the observations supporting and conflicting with a general rule. They also know how to reduce the weight of rules that almost don't apply, and to include rules that almost do apply.

Selection of alternatives and modeling timeliness. To simplify the modeling, we employ the same alternative selection model for experts and novices since most of the performance difference is in the quality of their situation interpretation. The output of the situation interpretation is similar for both expert and novices--a score of the match of the situation to the conditions required for candidate actions.

The alternative selection process itself, and the timeliness of this selection, are modeled using a variation of "Sequential Sampling Decision Models" (Pew, 1998). In our application of this technique, simulated decision makers sample the situation picture to score the applicability of the situation to each alternative, and then compare this score to a time dependent decision threshold. If the score of no alternative exceeds the threshold, they defer the decision. When the score of one of the alternatives exceeds the threshold, they pick that alternative.

Both the scores of the decision alternatives and the decision threshold change over time. The decision threshold normally decreases as the decision becomes more time-critical, reflecting the fact that as the decision deadline approaches, decision makers are willing to commit to an action with greater uncertainty as to the correctness of the decision. The scores of each alternative normally also change as the situation picture changes. For uncertain and ambiguous situations, these scores reflect the probabilities that the true situation has the actual properties needed to select one of the alternatives.

3 Conformance with Code of Best Practices

The modeling methodology follows the processes described in the draft Code of Best Practices, which specifies work to be performed preparing for and performing the C^2 analyses. The following relates the guidance in the Code of Best Practices to our methodology for modeling expertise in C^2 simulations.

3.1 Problem structure

The methodology for modeling expertise can be used to study many different issues in command and control. It's not confined to studies about the quality of human decision making under various circumstances, but can be used in examine any issue that the quality of decision making impacts. For example, it could be of value in trade comparisons of different types of aircraft, in which pilot tactics selection impacts the effectiveness of the aircraft.

The methodology requires that the problem be decomposed into a sequence of decisions, actions, effects, and situations assessments, as illustrated by the cycle of Figure 2. Decisions generate actions, which change the ground truth situation, which then changes the perceived situation picture, which then alters the situation interpretation and may generate another decision.

3.2 Human Factors and Organizational Issues

This methodology addresses human performance, as affected by stress or fatigue, and expertise, as impacted by training, experience, and decision aids. It is not intended to address either command style or organizational issues. Command style may be reflected, however, by modeling biases to risk avoidance or risk seeking. Organizational issues may be addressed by modeling multiple decision makers on the same team and by including communications in the situation picture.

As in most C2 simulations, scenario development requires specifying forces, equipment, missions, and possible actions. For the analyses described here, scenario development also includes:

1. Specification of levels of decision maker expertise of all simulated decision makers. Level of expertise is an independent variable, and is input as a separate parameter for each decision maker. These parameters determine the knowledge base content and reasoning processes used by the simulated decision makers.

2. Specification of the degree of familiarity of threat actions. Section 3.5, on models and tools, defines familiarity. Situation familiarity can significantly impact a decision maker's ability to interpret the situation correctly. Unfamiliar situations are likely to be unfamiliar, lack the usual sets of cues, and thus are hard to interpret.

3. Specification of the quality of the situation picture, input as a parameter. This parameter determines the degree to which the ground truth picture is degraded as the result of imperfect sensors, information processing limitations, and adversary information operations. Situation quality is measured by the accuracy, completeness, and precision of the situation picture.

3.4 Measures of Merit

The model requires measures of merit for expertise, for the difficulty of situation interpretation, and for decision output. These metrics are summarized in Tables 2 and 3 below. The metric for expertise and decision output is simple, and the metric for expertise is as specified in the Code of Best Practices, except that "meta synthesizer" replaces "creator" as a level of expertise. The metric for "difficulty of situation difficulty" is novel. Difficulty of interpretation depends both on the familiarity of the situation and on the quality of the situation picture.

Table 2. Metrics for expertise, decision quality, decision time, and situation difficulty.

Measured variable	Metric values
Expertise	Nominal: routinizers, analyzers, synthesizers, meta synthesizers
Decision quality	Nominal: correct, not correct
Decision time	
Time to recognize decision needed	Absolute value
Time to make decision	Absolute value
Situation "difficulty" of interpretation	Nominal: familiar-high quality, unfamiliar high-quality, familiar-low quality, unfamiliar low quality

Familiarity and the quality of the situation picture are inherently continuous variables. To simplify the analyses, however, each of these variables is represented as having one of

two nominal values, as defined below. The familiarity metric is based on theories of typicality in psychology in which the typicality of a object or activity is scaled in terms of the number of features the object or activity has in common with the prototype ranked most typical by groups of people. The quality metric is based on fusion and tracker metrics, such as those developed at the US Naval Research laboratory. Those measured the quality of a tracker in terms of numbers of reports correctly and incorrectly associated with the correct entity.

Table 3. Metrics for Difficulty of Interpreting the Situation Correctly

Situation Difficulty	Characteristics
Familiar	Fewer than x% of the actions in a tactic do not conform to doctrine, as defined by the ground truth tactics knowledge base.
Unfamiliair	More than x% of the actions in a tactic fail to conform to doctrine, as defined by the ground truth tactics knowledge base
High quality situation picture	• Fewer than y percent of ground truth objects are omitted; and • Fewer than z% of objects shown on picture are false alarms; and • The location uncertainty of all mobile objects is known within one standard deviation of sensor measurement accuracy, and • The correct identity is included in all identity estimates, and the probability associated with the correct identity is at least 50%.
Low quality situation picture	One or more of above criteria is violated.

3.5 Tools Models Used

This methodology for modeling expertise requires adherence to the Code of Best Practices guidelines on models and tools. For example, the processing of information must be represented explicitly when a situation picture is abstracted from a situation ground truth, and commander's decisions must be based on this situation picture.

The methodology requires four kinds of models specific to this approach:

1. **Knowledge base of doctrine and tactics**. Simulated actors' decisions specify actions to be taken. Automated or man-in-the-loop actors implement the decision by specifying a sequence of steps to carry out the decision. They may specify these steps from a doctrine look up table. Alternatively, they may identify the sequence using a planning system. The familiarity of the set of actions is scored by the fraction of generated actions that are specified by doctrine.

2. **Ground truth to situation picture converters**. These models act on each element of the situation. They can delete ground truth entities, add new false entities, move some of the entities from their ground truth position, and replace the ground truth identity with a probability list of possible identities. The fraction of ground truth elements

deleted, fraction of false elements added, distance moved, and probability assigned to ground truth identity depend on the situation quality parameter.

3. **Novice and journeyman decision models.** Decision models for routinizers and analyzers are rule sets. They specify the actions to be taken given various physical properties of the situation picture. The type of rules and inference logic is the same for routinizers and analyzers. However, analyzers have more rules, more connections among rules, and more cross checking among rules.

4. **Expert decision models.** These require three kinds of knowledge: 1) knowledge that describes the functional requirements for accomplishing a goal (e.g., penetrate to launch zone), 2) knowledge that specifies the various kinds of actions able to attain these functional requirements under various circumstances, and 3) knowledge that specifies what to look for in a situation picture if such actions are being carried out. Synthesizers and meta-synthesizers use the same type of models, but the meta-synthesizer knowledge base is more complete.

3.6 Experimental design

There are no special experimental design requirements associated with this methodology. The number of combinations for the levels of expertise, performance factors, and difficulty of interpreting the situation is potentially very large. Consequently, successful studies will likely require a careful experimental design.

Verification and validation of human knowledge bases and cognitive processes is very difficult, and formal V&V is probably not possible. V&V of the knowledge bases is usually accomplished by asking experts to review the decisions made by the modeled actors, in order to determine the correctness of the decisions given the available information.

3.7 Risks and Uncertainty

This methodology provides an efficient way to determine the sensitivity of C2 analyses results to decision maker performance, and to determine the sensitivity of the correctness of decision making to situation quality, tactics familiarity, level of expertise, and performance factors.

3.8 Reports

This methodology requires no special reporting formats and mechanisms.

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TACTICAL INFORMATION ABSTRACTION FRAMEWORK IN MARITIME COMMAND AND CONTROL

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1. SUMMARY

Various operational trends in naval warfare put the shipboard decision making process under pressure. As an example, there is a continuous advance in threat technology and an ongoing shift to crisis management scenario's in littoral waters. Data must be processed under time-critical conditions and, as a consequence, the risk of saturation in building a tactical picture increases.

In this complex context, the decision-makers need to gain a cognitive awareness of what is going on in their environment, by constructing a hierarchical situation model of this environment. This situation model consists of the basic elements present in the environment, relevant for understanding the situation. Furthermore, this situation model consists of combinations of interrelated elements, spatial and temporal structures, and abstractions expressing the situation at a functional and intentional level. Given our problem domain, maritime command and control, we will call this language according to which the situation model can be structured *Tactical Information Abstraction Framework* (TIAF).

The purpose of this paper is to derive and describe a maritime TIAF. This TIAF can be used as a language in which the result of data fusion can be expressed. If we are able to use a TIAF, according to which situation awareness can be structured, in the data fusion process, we can make a smooth match of this process with a situation awareness framework. Thus we will be able to integrate the human element into the design of a decision support system aiding the operators to achieve the appropriate situation awareness.

2. INTRODUCTION

At the heart of a shipboard combat system is a command and control system (CCS) by which the command team can plan, direct, control and monitor any operation for which it is responsible, to defend the ship and fulfil their mission. The increasing tempo and diversity of open-ocean and littoral scenarios, the technological advances in threat technology and the volume and imperfect nature of the data to be processed under time-critical conditions pose significant challenges for future shipboard CCS. Moreover, the ongoing shift to littoral warfare does also have a major impact on the maritime command and control process. In littoral areas, there generally is more commercial air traffic and more merchant shipping, potential threats can be multiple, with a high degree of uncertainty and only detectable at short ranges. As a consequence, due to saturation and high levels of uncertainty in the compilation of the tactical picture, the risks of taking wrong or inappropriate decisions increases.

This emphasises the need for warships to be fitted with an efficient combat system featuring a real-time, joint human-machine decision support system (DSS) integrated into the ship's CCS. This DSS consists in the combination of a multi-source data fusion (MSDF) capability, a situation and threat assessment (STA) capability, and a resource management (RM) capability (managing the ship's resources such weapons, sensors and communication means but also managing the ship's course and speed). These capabilities intimately match the four levels of the JDL (Joint Directors of Laboratories) data fusion model. One of the main roles of such a real-time DSS is to aid the operators to achieve the appropriate *situation awareness (SA)* state for their tactical decision-making activities, and to support the execution of the resulting actions.

The Decision Support Technologies Section at the Defence Research Establishment Valcartier (DREV, Canada) and the Maritime Command and Control group of the Physics and Electronics Laboratory of the Netherlands Organization of Applied Scientific Research (TNO-FEL, The Netherlands) are conducting research and development (R&D) activities in the field of decision support for Maritime Command and Control at the shipboard level. Investigations have been undertaken to study the concepts and design of a real-time DSS for their respective frigate in order to improve its performance against current and future threats. The Information Processing department of the TNO Human Factors Research Institute (TNO-TM, The Netherlands) is conducting research in the field of human-machine interface design for operations rooms and command information centres based on the analysis and modelling of C2 tasks and functions.

In view of the overlapping interest in studying and comparing applicability and performance of advanced state-of-the-art of Maritime Command and Control concepts and techniques, the research establishments involved have decided to join their efforts in conducting research in the area of Maritime command and control. By joining their efforts, Canada and The Netherlands are mutually increasing their potential for exploring a wider range of design philosophies, as well as the opportunity to benefit from participants previous experiences and lessons learned.

This paper presents a brief overview of one of these collaborative efforts which is focused at deriving a *Tactical Information Abstraction Framework* (TIAF) taking into consideration situation awareness concepts. *Situation awareness* is essential for commanders and their staff to conduct decision-making activities. *Data Fusion* is seen as an essential process to enable operators to achieve situation awareness. This purpose of the Data Fusion process can be served if the derived TIAF can be used as a language to express the situation awareness. It must be noted that the term Data Fusion does not only include the fusion of sensor data but also fusions at higher levels of abstraction (information integration).

This paper is organised as follows. Section 3 provides background information on the command and control (C2) process and the role of a decision support system in this process. Data Fusion and the role of situation awareness in dynamic human decision-making are also presented in this section. Section 4 motivates the need for a Tactical Information Abstraction Framework and proposes and exemplifies one. In Section 5 some issues related to data fusion system design are highlighted. Section 6 provides conclusions and recommendations, and discusses future work.

3. BACKGROUND

3.1 Command and Control Process

Command and control (C2) is the process by which the command team can plan, direct, control and monitor any operation for which they are responsible. In a naval context, most tactical decisions taken within the ship's operations room are made through a number of perceptual, procedural and cognitive activities constituting the C2 process. The C2 process is a suite of periodic activities which mainly involves the perception of the domain (environment), an assessment of the tactical situation, decision making about a course of action and the implementation of the chosen plan

The C2 activities are performed by either humans, machines (i.e., hardware and software computer systems), or a combination of both. Characteristics of this suite of activities are described in [Chalmers, 1997] and were captured through the Boyd's Observe-Orient-Decide-Act (OODA) loop illustrated in Figure 1. Although this loop might give the impression that C2 processes are executed in a sequential way, in reality, the processes are concurrent and hierarchically structured.

The military community typically states that the dominant requirement to counter the threat and ensure the survivability of the ship is the ability to perform the C2 activities (i.e., the OODA loop) quicker and better than the adversary. Therefore, the speed of execution of the OODA loop and the degree of efficiency of its execution are the keys of success for shipboard tactical operations. Decision support systems can contribute significantly to the fast execution of this loop.

3.2 Decision Support System

The complexity of the shipboard environment in which operators conduct C2 activities emphasises the need for warships to be fitted with a real-time decision support system (DSS). The main role of this DSS is to aid the operators in achieving the appropriate situation awareness (perceptual and cognitive) in order to support them in their tactical decision making and action execution activities.

Operators need to be aided by a DSS that continuously fuses data from the ship's sensors and other sources (MSDF capability), helps the operators maintain a picture of the tactical situation (STA capability), and supports their response to actual or anticipated threats (RM capability). In addition, the representation of knowledge in a meaningful way to the decision-maker is under the responsibility of the DSS.

Figure 1 presents the mapping of the MSDF/STA/RM system onto the OODA loop. The data fusion process, described in the next section, is seen as an important element of a DSS to provide the appropriate situation awareness to operators in support of their C2 activities.

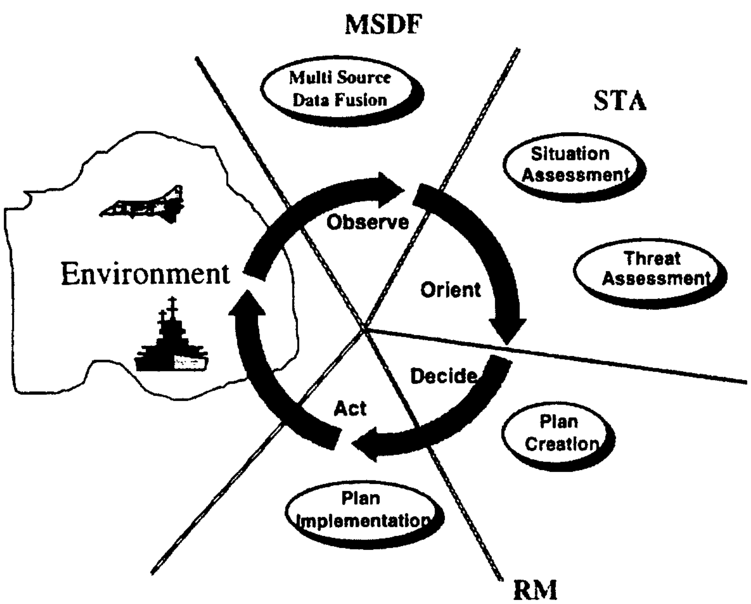

Figure 1: Mapping of the MSDF/STA/RM system onto the OODA loop.

Under time-critical conditions, automation is essential leaving the operator to a limited but essential role of go/no go decisions. In this context, DSS requires to be real-time efficient. When the tactical situation permits deliberation, tasks must be designed and developed to perform synergistically with the operator. This suggests that the design and development of a DSS to support the strengths and complement the weaknesses of operators by effective allocation of available resources to enable them to cope with the demands of the environment. For instance, taking advantage of the inductive intelligence of the human and deductive precision of the computer could lead to a joint human-machine system for the interpretation of complex tactical situation where the human is responsible to generate hypotheses and the machine responsible for the validation of these hypotheses against data.

Another general requirement for DSS is to support the human and to lighten his workload. This could be done through the automation of some simple deliberative tasks (i.e. commercial flight correlation) or by monitoring and aiding the combat operator during the execution of standard operational procedures in engagement situation. These enhancements have an impact on the interaction between the human-machine and modify the function allocation between them. For that reason, design and development of DSS requires taking into consideration the cognitive aspects of human information processing.

3.3 Data Fusion

According to the JDL model, DF is fundamentally a process designed to manage, organise, combine and interpret data and information obtained from a variety of sources, that may be required at any time by operators and commanders for decision making. It's an adaptive information process that continuously transforms the available data and information into richer information. Refined (and potentially optimal) kinematics and identity estimates of individual objects, and complete and timely assessments of current and potential future situations and threats (i.e., contextual reasoning) are achieved through continuous refinement of hypotheses or inferences about real-world events. The DF process is also characterised by the evaluation of the need for additional data and information sources, or the modification of the process itself, to achieve improved results.

Given these considerations, a complete DF system can typically be decomposed into five levels:

- Level 0 – Signal Data Refinement (source pre-processing);
- Level 1 – Object Refinement (Multi-Source Data Fusion (MSDF));
- Level 2 - Situation Assessment (SA);
- Level 3 - Threat Assessment (TA); and,
- Level 4 - Process Refinement through Resource Management (RM).

Each succeeding level of DF processing deals with a higher level of abstraction. Level 1 DF uses mostly numerical, statistical analysis methods, while levels 2, 3, and 4 of DF use mostly symbolic or Artificial Intelligence (AI) methods. Note that resource management in the context of level 4 fusion is mainly concerned with the refinement of the information gathering process (e.g., sensor management). However, the overall domain of resource management also encompasses the management of weapon systems and other resources (including the management of navigation and communication systems).

The JDL model provides a good description of the data fusion process. This process is an important element within the C2 cycle. One must also realise that the human plays an essential role in the C2 cycle. He is the one responsible for taking decisions. Because of the importance of humans, one needs a mechanism to reason about their role in the C2 cycle in order to facilitate the proper conceptualisation and design of DSS. Endsley [Endsley, 1995] showed that situation awareness is an essential precondition in this decision making process.

3.4 Situation Awareness

Endsley has derived a theoretical model of situation awareness (SA) based on its role in dynamic human decision making. Endsley defines situation awareness as the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. Figure 2 depicts the three levels of situation awareness as identified by Endsley.

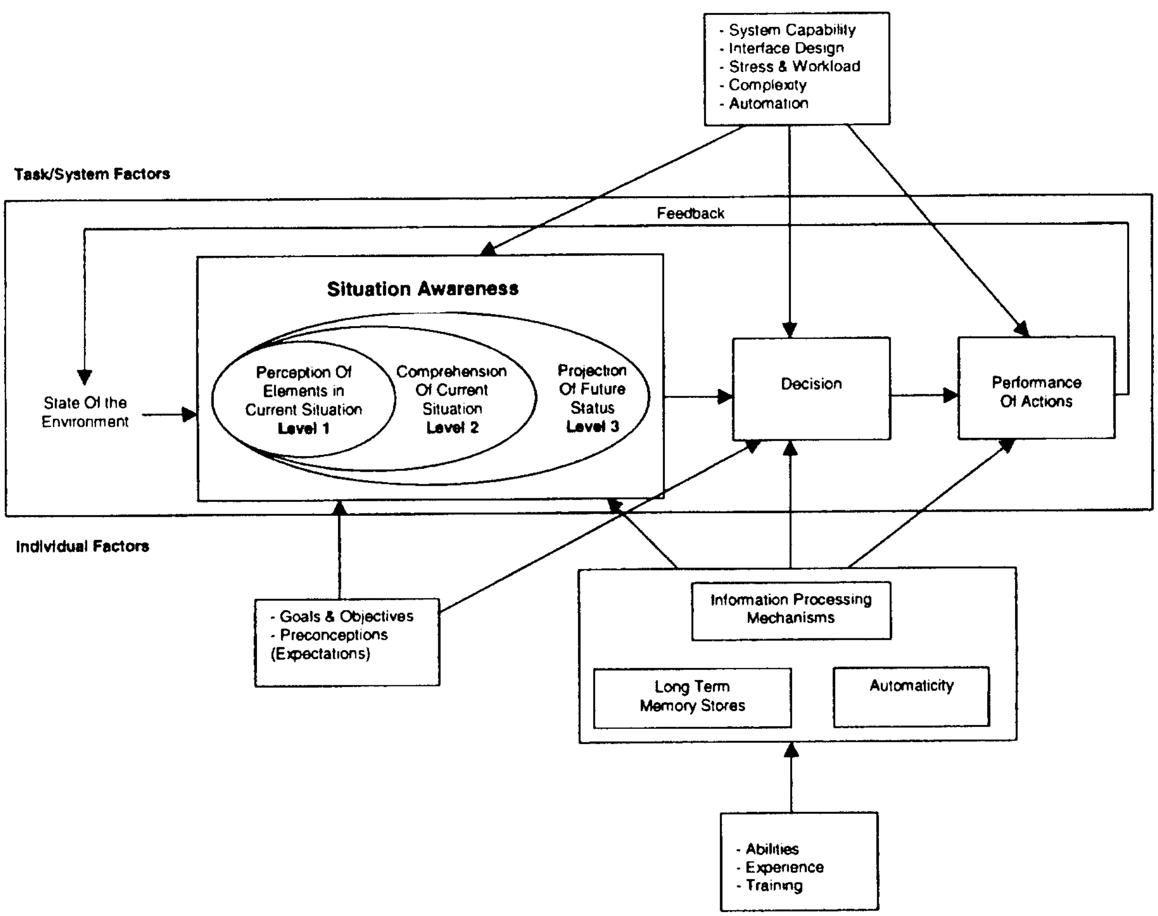

Figure 2: Situation Awareness model in dynamic decision making

SA can be interpreted as the operator's mental model of all pertinent aspects of the environment (process, state, and relationships). This mental model of the environment is also known in Rasmussen's work [Rasmussen, 1985, 1986 and 1996] as the *hierarchical knowledge representation* in decision-making. This paper focusses at the definition and application of this *hierarchical knowledge representation* in the context of naval C2.

Finally, bearing in mind the scope of this paper, one should note that SA could be achieved without the transformation and the fusion of data. For instance, training techniques typically enhance the operator's performance, resulting in a better SA. Similarly, advanced techniques in human computer interaction (HCI) allow a representation of the information in a meaningful way for the human.

4. TACTICAL INFORMATION ABSTRACTION FRAMEWORK

It has been shown earlier, by Endsley [Endsley, 1995] and Rasmussen [Rasmussen, 1985, 1986 and 1996] for example, but also [Carver, 1991], that human operators gain situation awareness of what is going on in the environment, by constructing a hierarchical situation model of this environment. In the description of the three awareness achievement steps, Endsley clearly presumes *patterns* and *higher level elements* to be present according to which the situation can be structured and expressed. This situation model consists of the basic elements present in the environment, relevant for understanding the situation. Furthermore, this situation model consists of combinations of interrelated elements, spatial and temporal structures, and abstractions expressing the situation at a functional and intentional level.

It would be beneficial if we are able to formalise the maritime situation model expressing the operator's situation awareness. The result of such a formalisation, a Tactical Information Abstraction Framework (TIAF), can be used in the development of decision support tools. Such support tools can optimally aid the human operator in gaining situation awareness, because the frameworks of both match. For the same reason, interactions between human operators and the decision support tools can be supported obviously, thus facilitating human-in-the-loop solutions.

4.1 Tactical Information according to STANAG 4420

In Appendix 1 of Annex A of STANAG 4420 [MAS, 1995] a Tactical Information Hierarchy is described. The purpose of the Tactical Information Hierarchy is to define the full range of tactical information required by the operational user at the command level. In this Tactical Information Hierarchy items are shown in a tree-like manner. This tree-structure represents several types of information and interrelationships. The tree represents objects[1] as well as attributes[2] of objects. For example: a *Track* is an object and *Kinematics* and *ID* are attributes of the track. Besides, several types of interrelationships are described in the tree:

- the relationships between an object and its attributes (Track and Kinematics for example)
- generalisation/specialisation relationships (for example: Track - (Track Description -) Surface Track - Combatant - Line)

In Figure 3 a part of the Tactical Information Hierarchy is depicted.

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[1] In [Rumbaugh, 1991] an *object* is defined as a concept, abstraction, or thing with crisp boundaries and meaning for the problem at hand. All objects have *identity* and are distinguishable. An object class describes a group of objects with similar properties, common behaviour, common relationships to other objects, and common semantics.

[2] According to [Rumbaugh, 1991] an attribute is a data value held by the objects in a class. Each attribute has a value for each object instance. An attribute should be a pure data value, not an object. Unlike objects, pure data values do not have identity.

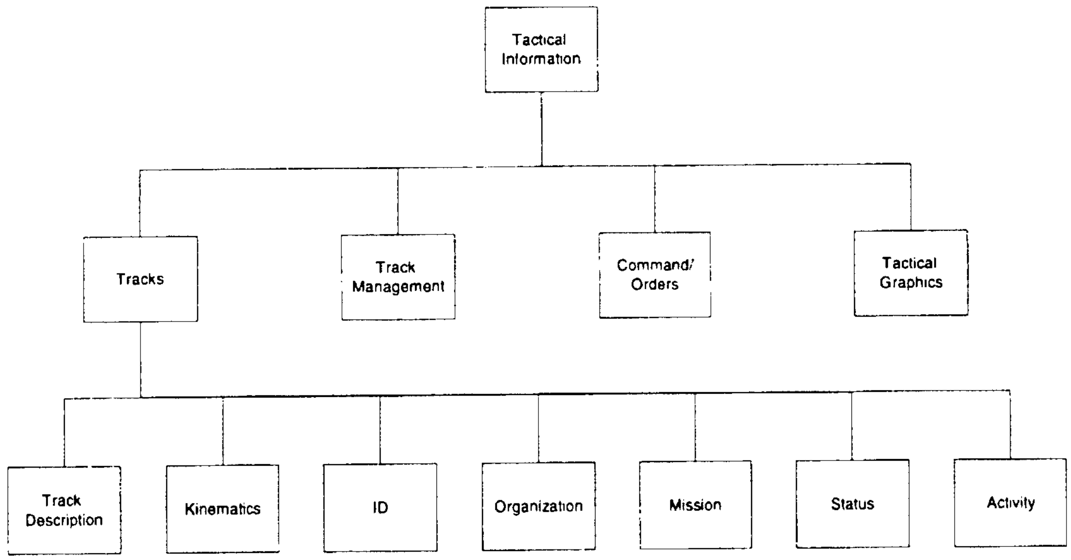

Figure 3: Part of the Tactical Information Hierarchy specified in STANAG 4420

The subtree of *Tracks* specifies all information about the entities in the environment.

- The *Track Description* subtree is a specialisation tree of Target types. The top-level specialisations are: Surface Track, Subsurface Track, Air Track, Land Track, Space Track, Special Point (such as Reference Point, Sonar Dip Position, Weapon Impact Point, etc.), Bearing (EM Intercept, Acoustic Intercept or Electro-Optical Intercept) and Own Track.
- The *Kinematics* subtree specifies all kinematic information considered relevant: Position (including History Points), Speed, Direction, Time and Rate (Rate of Turn and Rate of Climb).
- The *ID* subtree specifies the standard identity classes a target can be assigned to.
- The *Organisation* subtree specifies information about the organisation of Targets: Nationality, Alliance and Military Group (Task Force, Task Group, Task Unit and/or Convoy).
- The *Mission* node specifies the task or the mission of a Target or a group of Targets respectively (e.g. Reconnaissance, Escort, AAW, etc.)
- The *Status* subtree specifies various attributes regarding the status and the characteristics of a Target: Information regarding the Engagement of a Target, Availability of consumables, System readiness, Capability information and Strength.
- The *Activity* node specifies the type of activities that can be associated with mission and behavioural data based on kinematics.

4.2 What is missing?

What we like to express in our Situation Model is perfectly described in the purpose statement of the Tactical Information Hierarchy: *the full range of tactical information required by the operational user at the command level.* Given the characteristics of the derived Maritime C2 abstraction framework the following information is lacking:

- Some higher level abstractions (behavioural patterns at several levels)
- Rich representation of history (only history points)
- Explicit representation of interrelationships (Whole/part relationships are not shown in the tree. An example would be the relationship between a Military Group and its composing entities)
- Explicit representation of uncertainty (several types including uncertainty in detection, localisation, recognition and identification)
- Representations of capability information and intentions.

4.3 Rasmussen's abstraction hierarchy

Rasmussen et al. proposed a knowledge abstraction hierarchy with five levels ([Rasmussen, 1985], [Rasmussen, 1986], [Rasmussen, 1994]). This abstraction hierarchy was primarily meant to represent knowledge about a system for system management and diagnosis purposes (see Table 1)[1]. In [Rasmussen, 1986] he stresses that the description of a system can be varied in at least two ways. It can be varied independently along the abstract-concrete dimension, representing means-end relationships, and the dimension representing whole-parts relationships. Changes along the two dimensions are very often made simultaneously, but can in fact be done separately.

Rasmussen argues that such an abstraction hierarchy applies to so-called *causal systems* i.e. systems of which the response to an external influence is predicted bottom-up from causal laws. Furthermore he argues that a similar abstraction hierarchy applies to so called *intentional systems*, i.e. systems controlled in their response to external influence within their range of capability by their "intention" to act derived from the individual values structure and internal goals.

In summary the human's model of the world is a hierarchical representation; it enables recognition of objects an scenes at the level of physical appearance; it makes it possible to identify objects by their functional values rather than their appearance; and patterns of purposive behaviour can be activated by high-level intentions. [Rasmussen, 1986, page 93] A description of a system at a certain level of abstraction ('what') describes the 'why' of a lower level and the 'how' of a higher level. This holds for each level of abstraction.

4.4 Derivation of a Maritime C2 analogy

Starting from the ideas of Rasmussen, we can try to derive a maritime C2 analogy of the Abstraction Hierarchy.

4.4.1 Physical Form Level

If we look at our domain, maritime command and control, the basic element constituting our 'system' is an object in the environment (air target, surface target or subsurface target) regardless of its allegiance (friendly, neutral or hostile).

A target can be described using several kinds of attributes. In [Bossé, 1997] two main attribute types are distinguished: Positional attributes, representing the dynamic parameter describing the position and the movement of an object, and Identity attributes, i.e. declarations, propositions or statements that contribute to establish the identify of an object.

If we look at the way Rasmussen describes the Physical Form Level only a subset of these attributes is of relevance at this level. The system is described statically in terms of objects and their positions. So, only the Identity attributes and the current position of the targets is of relevance.

4.4.2 Physical Function Level

The Physical Function Level is oriented toward the functioning of physical components constituting our system, i.e. the functioning of the objects identified at the Physical Form Level. In our Maritime C2 analogy, the system is described in terms of dynamic behaviour of objects. At this level kinematic as well as non-kinematic behaviour of targets is relevant. Kinematic behaviour of targets can be expressed in terms of course, speed but also the fact that a target is manoeuvring. Examples non-kinematic behaviour are launching of weapons, use of (active) sensors and communication.

4.4.3 Generalised Function Level

The Generalised Function Level is the first level where the tie to the physical implementation (objects as well as processes) is cut. In our Maritime C2 analogy, the system is described in terms of *tasks* that must be performed, irrespective of the unit or the units performing it. Examples of such tasks are Conduct Search, Conduct Surveillance and Hunt and Destroy Submarines. Of course one platform may be better equipped to conduct a specific task than another platform, but essentially these tasks can be regarded irrespective of the tasked unit. As an example, a surveillance task can be assigned to a frigate as well as to a Military Patrol Aircraft (MPA).

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[1] In various sources, Rasmussen uses dissimilar terms for the Abstraction Levels. In this paper we will use the terms as shown in Table 1.

Table 1: System abstraction levels (after [Rasmussen, 1985] and [Rasmussen, 1994]).

Abstraction Level	*Properties represented*	*Characterisation*	*Example in the System Description domain*
Physical Form	Properties necessary and sufficient for classification, identification and recognition of particular material objects and their configuration; for navigation in the system.	At this level the system is represented in terms of the physical appearance and configuration of the system and its parts. The purpose of the system will control the representation to a certain extent.	Physical appearance and anatomy, material & form, locations, etc.
Physical Function	Properties necessary and sufficient for control of physical work activities and use of equipment: To adjust operation to match specifications or limits; to predict response to control actions; to maintain and repair equipment.	This level represents the physical processes of the system and/or its parts.	Electrical, mechanical, chemical processes of components and equipment
Generalised Function	Properties necessary and sufficient to identify the 'functions' which are to be co-ordinated irrespective of their underlying physical processes.	Descriptions at this level deal with functional relationships that are widely found independent of material manifestations. Generalised functions are structured according to available models of functional relationships.	"Standard" functions & processes, control loops, heat-transfer, etc.
Abstract Function	Properties necessary and sufficient to establish priorities according to the intention behind design and operation: Topology of flow and accumulation of mass, energy, information, people, monetary value.	At this level, the overall function of a system can be represented by a generalised causal network, e.g., in terms of information, energy, or mass flow structures reflecting the intended operational state.	Causal structure, mass, energy & information flow topology, etc.
Functional Purpose	Properties necessary and sufficient to establish relations between the performance of the system and the reasons for its design, that is, the purposes and constraints of its coupling to the environment.	At the highest level of abstraction, the purpose or intended functional effect of a system is described.	Production flow models, control system objectives, etc.

4.4.4 Abstract Function Level

The Abstract Function Level represents the concepts that are necessary for setting priorities and allocating resources to the various general functions and activities at the level below ([Rasmussen, 1994]). In other words at the Abstract Function Level the generalised functions identified at the Generalised Function Level are regarded in interrelation with each other. The overall functioning of the system, determined by the co-functioning of all the elements of the system, is regarded.

In our Maritime C2 analogy, the system is described in terms of a network of co-operating tasks. Generally, a number of tasks, each with a specific goal, together serve a higher level goal or mission. While the Generalised Function Level describes the system in term of individual tasks carried out, this level interrelates these tasks and focuses on the contribution, the added value of the tasks to the full system.

As an example, consider a hostile frigate equipped with surface-to-surface missiles and a hostile fighter. The fighter is tasked to search and acquire our platform. The hostile frigate has an Anti Surface Warfare (ASuW) task. Both tasks are interrelated. The results of the search and acquisition task can or even will be used in the ASuW task to be able to target the missiles.

4.4.5 Functional Purpose Level

The highest level of functional abstraction represents the system's functional meaning. What is the purpose of the existence and the dynamic behaviour of all the objects constituting the system. In our Maritime C2 analogy, the system is described in terms of missions or better[4]: intents. In our system their will generally be a number of (often conflicting) intents.

As an example consider a task force with the mission to protect a High Value Unit (HVU). Three different tasks can be distinguished to fulfil this mission: Conduct Reactive AAW, Conduct Reactive ASuW and Conduct Reactive ASW. Each of these tasks serve a common goal, namely protection of the HVU.

4.5 Example

In this section we will illustrate the derived abstraction hierarchy by means of a simple scenario. The scenario is derived from a scenario described in [Miles, 1988] and is depicted in Figure 4.

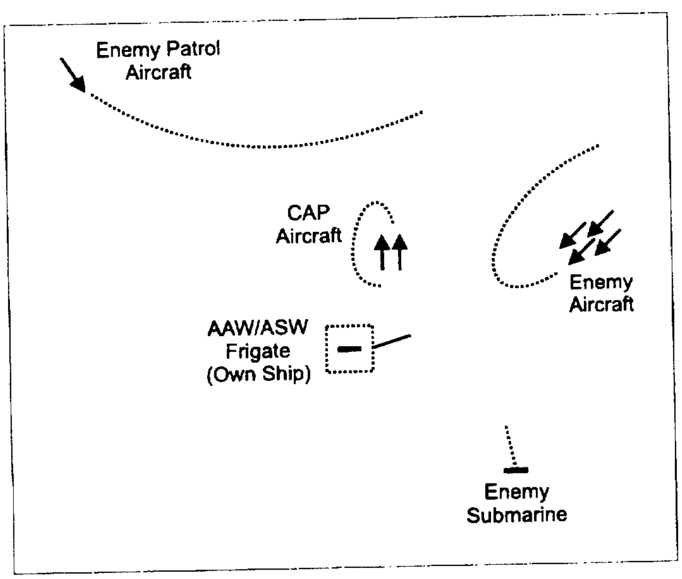

Figure 4: Simple scenario

Our own ship is a frigate with an Anti Air Warfare (AAW) and an Anti Submarine Warfare (ASW) task. We have a Combat Air Patrol (CAP) at our disposal consisting of two fighter aircraft. An enemy Military Patrol

[4] The term *mission* in a Maritime C2 context often denotes more than just *purpose* or *objective*. Mostly, it includes a description of *how* an objective can be achieved (an operation) as well. See for example [Delmee, 1998]

Aircraft (MPA) enters the picture from north-west. Its purpose is to locate our ships and guide other units to attack. One possibility for attack is an enemy submarine in the south-east sector. Another element for attack is a group of strike aircraft which fly in from the east to launch missiles at our ship.

In Figure 5 the situation awareness during the scenario aboard our own frigate is depicted. Two distinct time steps are represented, separated by a vertical dashed line. The five abstraction levels are separated by the horizontal lines. Observations are greyed and can typically be found at the two lowest abstraction levels. Derived hypotheses are placed at the abstraction level where they belong.

At the first time step our radar system detects our own CAP. This detection corresponds with its planned position. Our ESM-equipment detects an emission in north-west direction. This emission can be recognised as an enemy patrol aircraft. There are no sonar contacts. Finally, there is an intelligence report, reporting an enemy aircraft of a specific type in eastern direction, heading west. These observations and reports belong to the first two levels of abstraction. Some observations, such as radar detections for example, indicate presence and/or position of an object in our environment. Other observations, such as the fact that the enemy aircraft is heading west, indicate dynamic behaviour of an object. Yet other observations, such as ESM-detections, indicate both. ESM-detections reveal the presence of an object, they may also provide evidence for the type and the activity of the object.

If we combine the observations done in the first time-step, propositions belonging to higher abstraction levels can be derived. As an example, the fact that we have a recognised ESM-contact in north-west direction while it is not possible to correlate radar contacts with this contact, gives evidence to the proposition that the enemy MPA is beyond the radar range. An MPA can typically be used to shadow our ship. The ESM indicates this activity. This shadowing or search task is a proposition at the Generalised Function level. This search activity is not a goal in itself. A search activity typically provides input to other units (Abstract Function level). If the search-proposition is combined with the reported enemy aircraft, a Functional Purpose proposition of an air raid from the east can be derived.

At the second time step new observations are done. Like we did in the first step, higher level propositions can be derived from these observations as well. Eventually, we arrive at two Functional Purpose propositions, representing an air attack and a submarine attack.

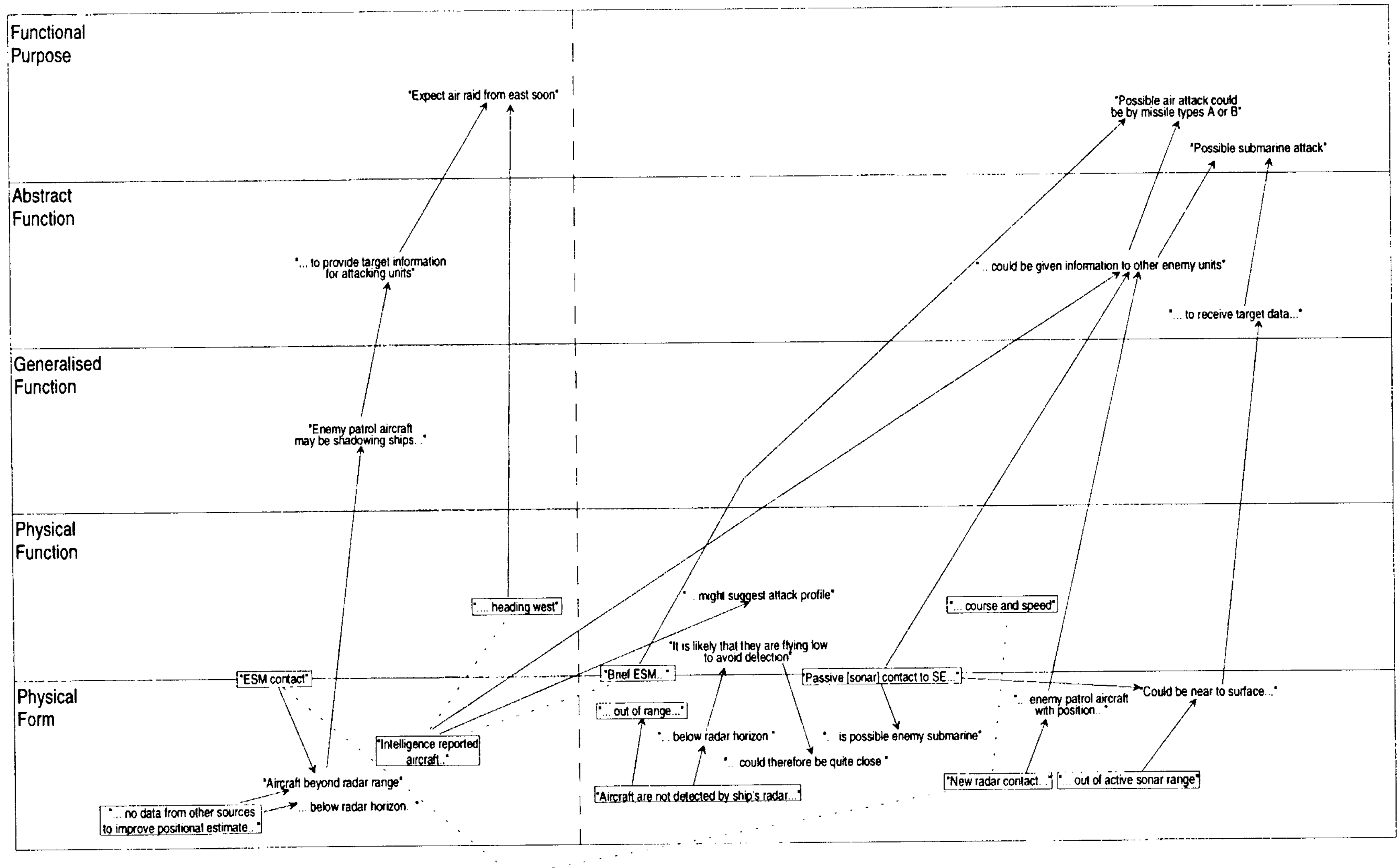

Figure 5: Example of application of abstraction levels. The boxes represent observations, the dotted lines represent correlation of observations and the drawn arrows represent reasoning steps. Reasoning as well as time proceeds from left to right.

4.6 Résumé

In Table 2 the derived Maritime C2 analogy is summarised and exemplified with references to the example scenario given in the previous section.

Table 2: Maritime C2 analogy derived from Rasmussen's Abstraction Hierarchy

Abstraction level	*Maritime C2 analogy*	*Typical aspects*	*Example*
Physical Form	Target	Observable attributes (RCS, IR-image, visual image, ...)	MPA
Physical Function	Dynamic Behaviour	Kinematics, course, speed, manoeuvring Yes/No, EM-emission, ...	Flying in NW direction, ESM-emission
Generalised Function	Behavioural Patterns, Tasks	Searching, Acquiring, Attacking, ...	Searching
Abstract Function[5]	Functional co-operation	Functional co-operation of units; roles of units in a functional group	Enabling a frigate to engage us
Functional Purpose	Mission	Intent	Submarine attack

The real-life objects in the environment of our own ship can be represented by object propositions at five levels of abstraction. The propositional or hypothetical nature of these objects can be found at several places in the example described in Section 4.5. Gaining, increasing and maintaining situation awareness essentially boils down to reasoning among those propositions. Furthermore, at each level of abstraction whole-part relations can be found. At the physical form level whole-part relations represent aggregations of units, such as formations and dispositions. At the Generalised Function level, for example, functionally interrelated tasks can be aggregated. The functional interrelations themselves belong to the Abstract Function level.

5. DATA FUSION SYSTEM DESIGN ISSUES

What is the benefit of structuring the propositions representing our awareness of the situation like we proposed in the previous sections? In present systems, construction of a picture of the environment is only supported at the lowest abstraction levels. The Recognised Maritime Picture represents individual targets, their types, their identity, their positions and their kinematics. Of course, for self-defence purposes this is very important information. The information we represented at the higher levels of abstraction is very important if we look at longer term planning and decision-making activities. Current systems have very poor means to derive or even represent this type of information. Decision-makers, needing awareness of the situation at these higher levels of abstraction can hardly receive support from present systems in gaining this awareness.

A first step towards development of support in this process of gaining awareness is identification and formalisation of the propositions constituting the description of the situation at the higher abstraction level. We feel that it is possible to use the TIAF in the process of gaining situation awareness by regarding this process as a number of co-operating Data Fusion Agents (Figure 6) interconnected by a network, which is structured similar to the structure of the TIAF derived in the previous section. For a detailed foundation see [Paradis, 1998b].

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5 The transition from the level of generalised function to that of abstract function is probably most evident when considering information-processing systems. Here, a set of coding conventions relates the actual functioning of the system at the physical and generalised levels to the abstract function in terms of information processes. The abstract function represents the semantic content of the physical signals and, hence, the overall organising principle. ([Rasmussen, 1986])

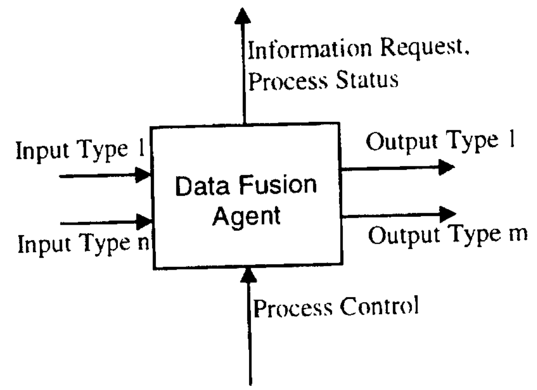

Figure 6: Generic Interfaces of a Data Fusion Agent

A model of the data fusion process structured according to the given description, is depicted in Figure 7. The data fusion agents are interconnected according to a TIAF. The agents are controlled by a process refinement process, based upon explicit requests for information and the process status of the data fusion agents.

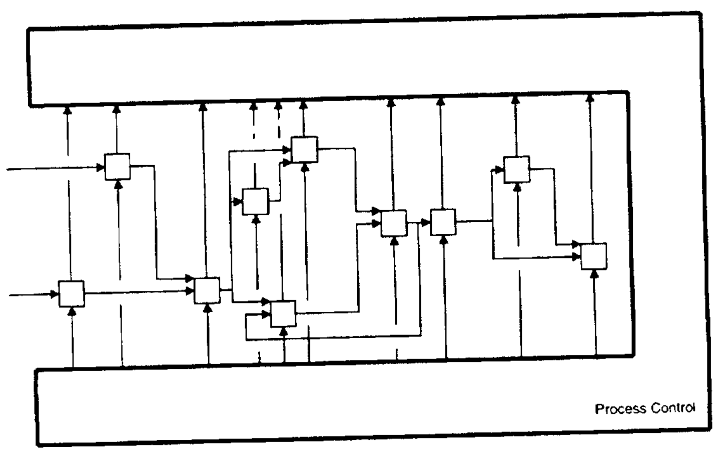

Figure 7: Co-operating Data Fusion Agents

Figure 7 doesn't depict any realistic data fusion system. It attempts to visualise the concept of co-operating data fusion agents. Most often, outputs from lower level data fusion agents flows provide input for higher level data fusion agents. In level 1 an example is depicted of an agent, using higher level information to enhance the result of level 1 processing. In [Paradis, 1998a] this concept has been illustrated in detail.

In a Data Fusion model as depicted in Figure 7 the role of a human operator can be modelled as a number of Data Fusion Agents. Feasibility of automation of the Data Fusion process is beyond the scope of this paper. Apart from *feasibility* of automation however, it is debatable whether or not far-reaching automation of the Data Fusion process is *desirable*. Recall that the Data Fusion process can be seen as a process of gaining situation awareness. It may be better to primarily *support* the human in the process of gaining situation awareness rather than *automating* it. The primary goal is to provide the human with a better understanding of what is going on, in order to enable him to do a better assessment and decision-making job. If the system does the process of constructing a model of the situation, leaving the actual assessment of the situation to a human being, there is a serious risk that the human being will get his wires crossed sooner or later because he cannot keep step with the reasoning process of the system. See also [Lipshitz, 1997].

If it is possible to represent a maritime data fusion process as described above a blackboard architecture will be a promising architecture for such a data fusion system. See for example [Paradis, 1998b] and [Corkill, 1991]. In de DRESUN testbed [Carver, 1991] a blackboard has been successfully applied.

6. Summary, Conclusions and Suggestions for Further Work

The Tactical Information Abstraction Framework (TIAF) described in this paper, can be used to structure the process of gaining situation awareness but also to structure the assessment process. Assessment functionality can be identified at each level (the physical target level up to the intent level). Threat assessment presently focuses primarily on the target level. The Threat assessment process can be improved by explicitly considering higher abstraction levels as well. Probably, we can even take this a step further. Resource Management can be seen as a multi-level activity as well. It may be possible to extend the levels distinguished in this paper to Resource Management.

A data fusion system can be designed by combining the ideas of this paper with the ideas of [Paradis, 1998a] and [Paradis, 1998b]. In [Paradis, 1998b] the notion of data fusion agent is introduced. These data fusion agents can be interrelated conform the TIAF described in this paper.

If you use the abstraction framework for representation of the objects in the environment, more abstract objects can be derived from less abstract ones. More abstract information, on the other hand, can be used to refine less abstract objects (see [Paradis, 1998a]). If you combine these derivation and refinement activities carelessly, then there is a data looping risk, i.e. a risk that a proposition indirectly serves as evidence for itself ([Bossé, 1997]).

We referred to a Standardization Agreement on Display Symbology and Colours for NATO Maritime Units [MAS, 1995]. We found that the Tactical Information Hierarchy in this STANAG was inadequate for our purpose. This Tactical Information Hierarchy however, formed the basis for a display symbology described in the STANAG. In this paper we proposed a structure for the information required by an operator to gain insight in what is going on in the environment. To enable this operator to interact with a computer system supporting him in this process, it may be necessary to adapt or extend the symbology specified in [MAS, 1995].

The promises of applying the TIAF as proposed in this paper must be verified. For this verification, scenario's must be developed as well as Measures of Performance and Measures of Effectiveness. Furthermore, the knowledge necessary for derivation of higher level abstractions from lower level ones must be acquired and structured in a maintainable and accessible way.

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MISSION EFFICIENCY ANALYSIS OF TACTICAL JOINT COGNITIVE SYSTEMS

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DESCRIPTION OF THE PROBLEM

It is imperative that effective C3I in military operations ensures that a sufficient amount of information reaches the intended decision-maker in time, and that the information management system sustains the execution of a mission without excessive delay and friction. Information and intelligence must fulfil stringent requirements of reliability, availability, relevance, and diagnosticity. One of many purposes of tactical integrated C3I systems is to secure an omnidirectional, continuous flow of information from the division level down to the platoon and squad levels. Sometimes even individual soldiers and sensor systems must without delay be allowed to affect the decisions and actions of a higher-echelon commander.

ISSUES

The main objective for our research undertaking is to actively take part in the fulfilment of the needs mentioned above, and thereby also contribute to the field of C3I system design, assessment and evaluation. In this paper we outline our work on development of theories and models for acquisition, processing and representation of safety- and time-critical information, intended to aid decision makers performing complex tactical operations. We also tested these concepts in several simulated tactical operations, and finally, validated the concepts in a number of full-scale exercises. Our contention is that integrating relevant and effective methods and tools for analysis, synthesis and development is of the utmost importance to achieve successful improvement of command and control procedures as well as to successfully design and operate future command and control systems.

METHODOLOGY/APPROACH

We pursued a broad research approach, with focus on tactical battle management and emergency response issues, and adopted a combined theorist's and practitioner's perspective to discover novel and effective ways to model and analyse tactical response units and their missions. This was accomplished by developing a mission efficiency analysis (MEA) technique for mission performance evaluation and assessment, and investigating the implications on command and control during such missions. Briefly, the MEA technique was used in the following research work:

- Identification, modelling, and synthesis of distributed dynamic decision making and other command, control, and intelligence processes, by means of case studies, field studies, and experiments.
- Identification and analysis of factors that cause limited or sub-optimal performance in command, control and intelligence tasks, by investigating the need, flow, and processing of information and intelligence in military and other high-risk operations

MEASURES OF MERIT: THE MISSION EFFICIENCY MEASURE

Experiences from our initial work on military units made it possible to integrate a dynamic system model with Cognitive System Engineering (CSE) and associated process control concepts. The author (Worm, 1998b) developed a set of methods and tools for modeling, analysis, and evaluation of tactical military units and their performance: mission skills, commander mission resource management, and overall unit performance. The central point of this project was the integration of a number of methods and tools, used for many years in trade, industry, and systems development, into a multi-discipline mission and unit evaluation and assessment technique. To facilitate this integration, a set of concepts was introduced in order to analyze and evaluate the accomplishments and shortcomings of various tactical units in an unambiguous and comprehensive way.

The concepts were:

- Control theory-based conceptual modeling of dynamic and complex mission systems and processes, and of their states and state changes.
- Identification of mission processes, their state variables, and of different action and decision making mechanisms as a mission process regulator.
- Performance evaluation and efficiency analysis of fully manned and equipped units, executing authentic tasks in a realistic mission environment, provided by an innovative system for instrumented mission training, described in (Morin et al., 1998).

We developed and improved the applicability of these concepts from the military domain (Worm, 1997) into a generic *Mission Efficiency Analysis (MEA)* technique (Worm et al., 1998b). This was achieved mainly by extending the conceptual framework to cover larger, more diverse, and temporarily organised forces, and by making use of a more general terminology. This leads us to the definition of the mission efficiency measure.

DETERMINING THE MISSION STATE

By the term *Mission State* at a given time is meant a set of information, i.e. variable values that makes it possible to determine future output if future input is known.

Before the mission, the mission has an *initial state.* When the activity, function, status or mission objective of the unit changes, due to any cause, a *mission state change* takes place. The initial mission state are primarily determined by the factors described in Figure 1.

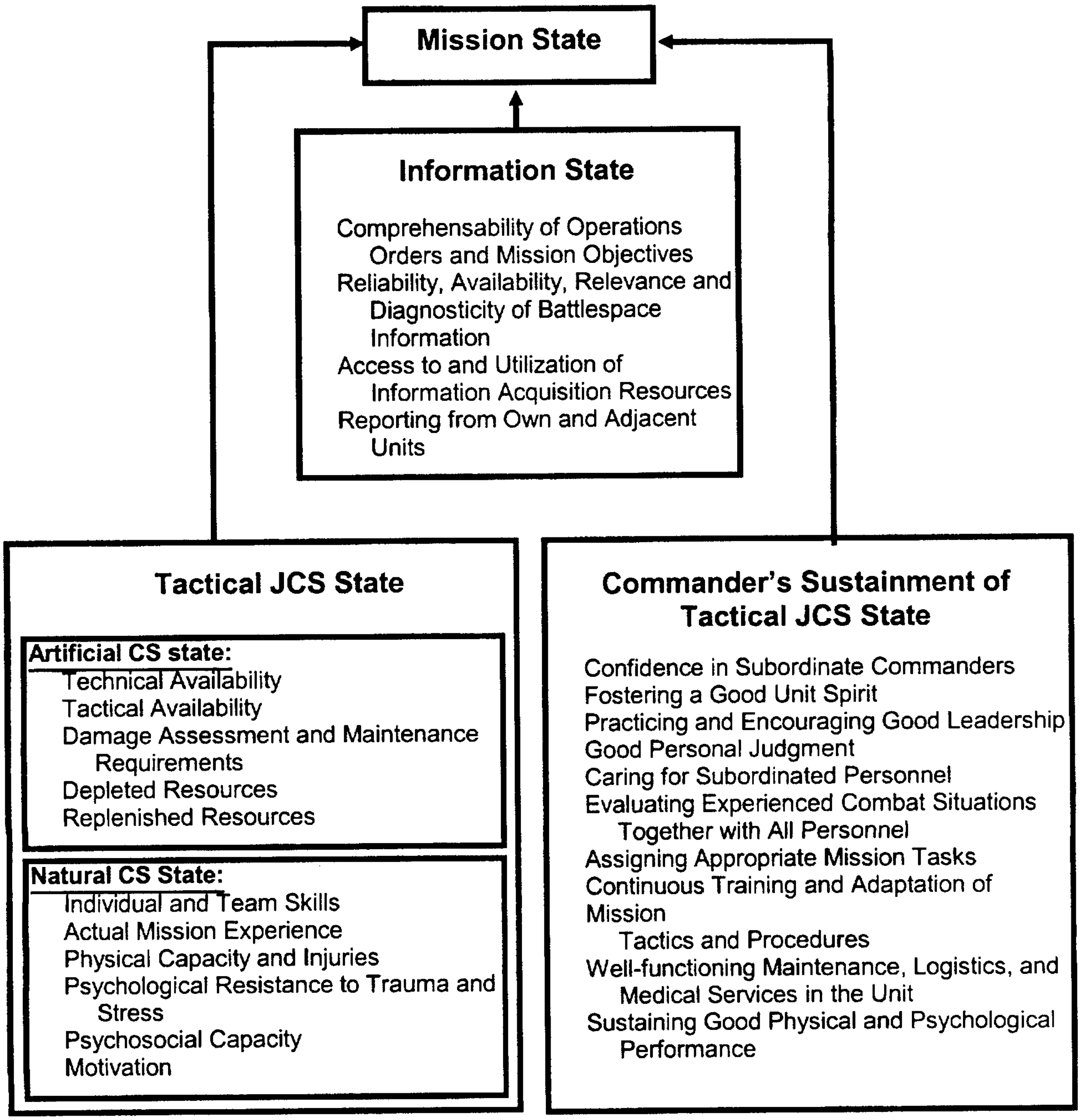

Figure 1. Schematic Description of Mission State Determinants.

Information Processing During the Mission

The ability of the mission commander and staff to manage and process the information available at the time of mission execution is analysed. The most important factors for a successful outcome are

- Information acquisition performance
- Information processing performance
- Information sharing and distribution effectiveness

Utilisation of Available Resources During the Mission

The management and utilisation of available resources are analysed by studying

- Resource depletion
- Resource replenishment
- Resource allocation
- Unit recovery and reorganisation
- Time relations at critical decision points

Decision Making and Actions During the Mission

Decisions and actions of the mission commander and staff are documented, along with the information related to the mission that was available at the decision points. Crucial properties are

- Information relevance to the actual decision situation
- Information reliability
- Information availability
- Information diagnosticity
- Time relations at critical decision points

Mission Course of Events

The course of events was registered and reconstructed by using the MIND system described below. All available information was presented synchronised in time, and put into its proper context, in order to create an elaborate description of a chemical warfare scenario.

The mission efficiency definition, its determinants and their relations to the mission efficiency measure are illustrated in Figure 2.

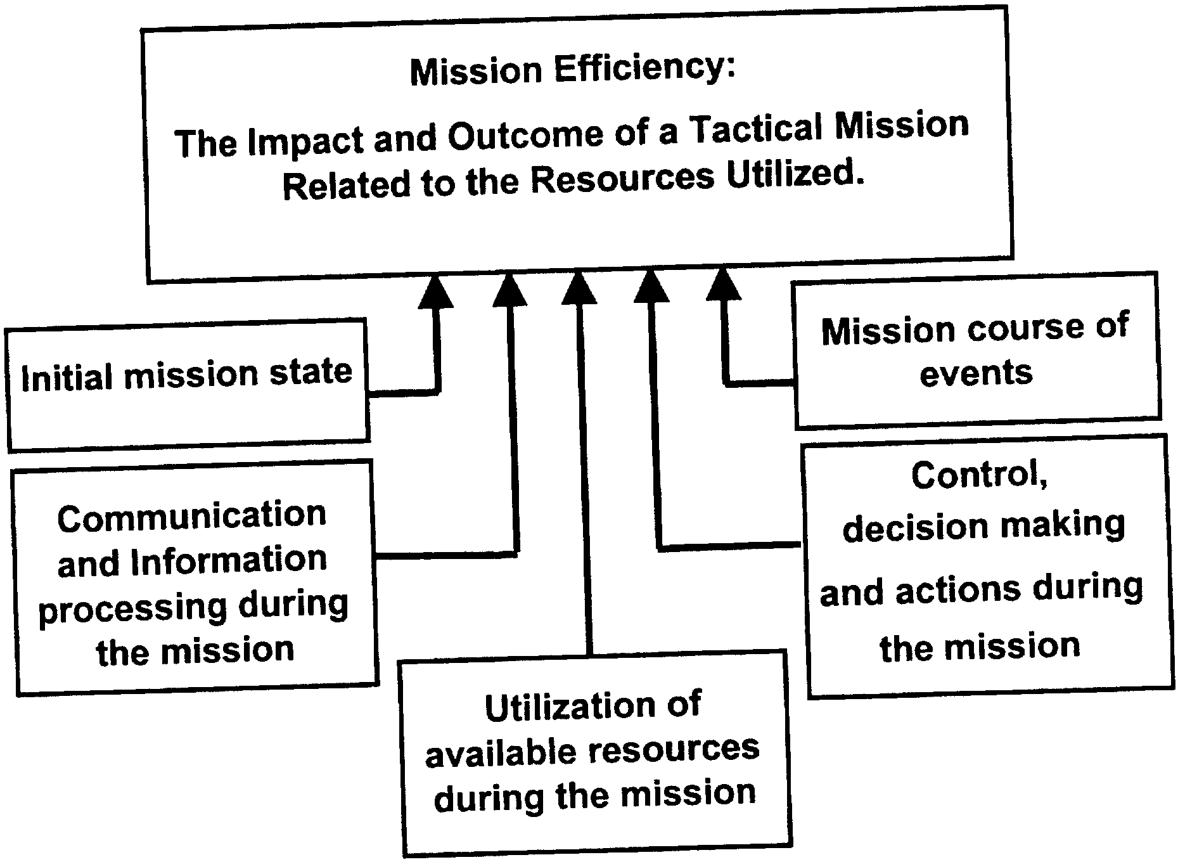

Figure 2. Definition and determinants of the mission efficiency measure.

MODELS USED: TACTICAL JOINT COGNITIVE SYSTEMS

The striking properties of tactical forces performing hazardous, time-critical operations can be characterised in brief as improved mobility and lethality, increased risks and resource requirements, and complex decision making and action selection situations (Worm, 1997). These dynamic properties raise a demand for increased personal and equipment performance requirements, and escalating needs for personal protection. Military commanders of today, and to an even greater extent in the future, will face dynamic and non-linear C^2 problems. Implementing modern C^2 principles requires advanced human, organisational, and technical resources with very high information processing capabilities. Modern C^2 systems demonstrate true real-time properties at all levels; the individual soldier and weapon system as well as where the systems are integrated into higher-order structures, such as joint operations forces. This calls for unique and innovative approaches to the mission C^2 problem. Improving operator and commander abilities to train, assess, evaluate, and master these belligerent dynamics will have decisive impact on all decisions and selections of action, mission course of events, logistics, the number of casualties, and many other vital components of emergency response or other kinds of severe crisis (Worm, 1998). However, the specific skills and properties that managers and operators have to possess

in order to yield optimal mission performance in such critical and uncertain situations are not easily identified, and hence, they are difficult to improve (Morin, et al., 1998a).

A major problem in addressing a topic area with such a vast scope is to fulfill a number of diverse and many times conflicting requirements for supporting C^2. Based on studies performed during military instrumented force-on force exercises (Worm, 1997), together with two studies in the emergency response domain (Worm et al., 1998a), (Worm et al., 1998b), we concluded, that in most situations, the following command-and-control-related factors cause limited mission performance:

- The ability to rapidly and accurately build and sustain individual and team situation awareness, causing difficulties in selecting alternative actions when the situation and the course of events changed in an unanticipated way.
- The access to and use of a mission information structure which supports and improves real time information and intelligence acquisition, and permits mission-relevant information and intelligence to reach the intended decision maker in a timely manner.
- The ability to explicitly formulate resource needs coupled to the mission at hand, and to allocate adequate and available resources to facilitate optimal mission accomplishment.

Using our experiences from the studies mentioned before, we began trying to define the systems studied utilizing a common frame of reference. One major conclusion concerned the properties and abilities of forces performing tactical, hazardous operations. The demands imposed on forces performing *tactical operations* were defined as requirements for performing hazardous, time-critical operations whose main characteristics follow below:

- Rapid and reliable, manual and automated information acquisition and processing.
- Distributed team decision making in dynamic environments.
- Wide-band communications with high resistance to jamming, between and within units engaged in the mission.
- Highly efficient, agile, robust, and adaptable to a multitude of missions and tasks.
- Constantly exposed to risk for own and others' lives and property.
- Striving to meet ever-increasing performance requirements by means of advanced training.
- Capable of coping with complex and ambiguous decision and action selection situations.

These dynamic properties call for unique and innovative approaches to the problem of modeling the dynamics of tactical missions. Similar demands are also imposed on the modeling and analysis of the units performing such missions. The identification and specification of optimal performance requirements in such critical and uncertain situations are cumbersome tasks that are often subject to misinterpretation.

DEVELOPING A MAIN SYSTEM MODEL: THE TACTICAL UNIT

By the term *dynamic system* is meant, in control theory, an object, driven by external input signals *u(t)* for every *t* and as a response produces a set of output signals *y(t)* for every *t*. From the work of Conant and Ashby, (1970), Brehmer, (1992), and Ljung & Glad, (1995), it is well known that most complex systems have *real-time, dynamic properties*; the system output at a given time is not only dependent of the input value at this specific time, but also on earlier input values, and that a good regulator of a system has to implement a model of the system that is to be controlled. Put otherwise, Ashby's law of requisite variety (Ashby, 1956), states that the variety of a controller of a dynamic system has to be equal to or greater than the variety of the system itself. This implies the tactical robustness and adaptability characteristics identified earlier. The basic principles of human-centered automation (Billings, 1996) provided a thorough and clear-cut set of requirements to make the mission and unit modeling comprehensive and explicit. The principles are based on a premise:

- Some human practitioners bear ultimate responsibility for the achievement of operational goals.

This premise is the followed by an axiom that states:

- These supervisory human operators must be in command.

To bear responsibility, and hence, to be *in control* of a tactical operation, operators and commanders involved must be *in command*. Billings basic axiom supports this by the following corollaries: To be in command within one's range of responsibility, a human operator

- must be involved;
- must be informed;
- must be able to monitor the automated, technological systems, or other subordinate agents;
- must be able to comprehend and predict the behavior and performance of such agents;
- must be able to communicate it's intent to other system elements, and to track and acquire the intent of other system elements.

Consequently, we identified the *main system* in a tactical mission process as the system

- to which a mission is assigned;
- to which the operational command of the mission is commissioned;
- to which the responsibility for effecting the mission is authorized;
- to which the resources needed for performing the mission is allocated.

We designated this main system as the **Tactical Unit,** an aggregate consisting of one or several instances of three principal sub-system classes:

Technological Systems, for example vehicles, intelligence acquisition systems, communication systems, sensor systems, life support systems, and other kinds of mission-specific equipment, including the system operators. The terminology used in Cognitive Systems Engineering (CSE)

proved to be quite adequate for describing and modeling technological systems and human operators, as Artificial Cognitive Systems (ACSs), and Natural Cognitive Systems (NCSs), respectively (Hollnagel and Woods, 1983), (Hollnagel, 1997). The complete system, where the technology and the operator together performs a complex task, could correspondingly be described and modeled as a Joint Cognitive System (JCS), (Hollnagel, 1997).

Command and Control Systems, consisting of an information exchange and command framework, built up by technological systems and directly involved decision makers, arranged in a hierarchical or quasi-hierarchical system (Brehmer, 1988). Three examples of hierarchical or quasi-hierarchical command and control systems outside the obviously hierarchical military domain are:

- Emergency Management Command and Control Systems
- Surface Transportation Surveillance and Control Systems
- Air Traffic Control systems

Support Systems, comprising staff functions, logistic functions, decision support functions, organizational structures, and other aiding and assisting services.

Also in these two last cases, the CSE framework yielded a powerful ability to describe and model these systems as joint cognitive systems.

TEAMS AND TEAM PROCESSES IN TACTICAL UNITS

We chose to use the concepts of (Salas et al., 1992) to define a team as "Two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have been assigned specific roles or functions to perform, and who have a limited life-span of membership.". The primary issue of the definition was that task completion required support of the following processes:

- A dynamic exchange of information and resources among team members,
- Co-ordination of task activities (for example active communication, back-up behaviors),
- Constant adjustment to task demands, and some organizational structuring of members.

This implies that novel solutions to the problems of performing efficient tactical operations must be focused at investigating the nature of these team processes together with analysis and synthesis of different means to support and control them. As a result of our work on studying, modeling, and evaluating tactical units and tactical teams, we concluded that these systems could be described making use of a common CSE framework, and therefore we define these as tactical joint cognitive systems (TJCSs).

THE MISSION MODEL: A PROCESS CLUSTER

Missions can be described as aggregates of systems and processes, arranged in a dynamic process cluster, depicted in Figure 3, next page. The importance of balance between feedback (reactive) and feedforward (proactive) control is crucial to achieve optimal C^2 performance in a tactical mission. If the system output is used to determine the system, there is only a limited need for knowledge of system

dynamics. You can then continuously make necessary adjustments by measuring the deviation of the system output from the reference value.

If not the system output is available for observation and measurement, you must have exact knowledge of the system input's influence on the system output. In some cases the disturbances can be measured. It is then possible to almost entirely eliminate the influence of those disturbances by using feedforward. However, this requires an extremely good system knowledge of the process that we wish to control. Feedforward control is also sensitive to variability in the system dynamics. The main advantage of feedforward control is the possibility to counter the effects of disturbances before they are visible as an undesired deviation from the reference. Feedforward control is often combined with feedback control because of its practical reliability limitations.

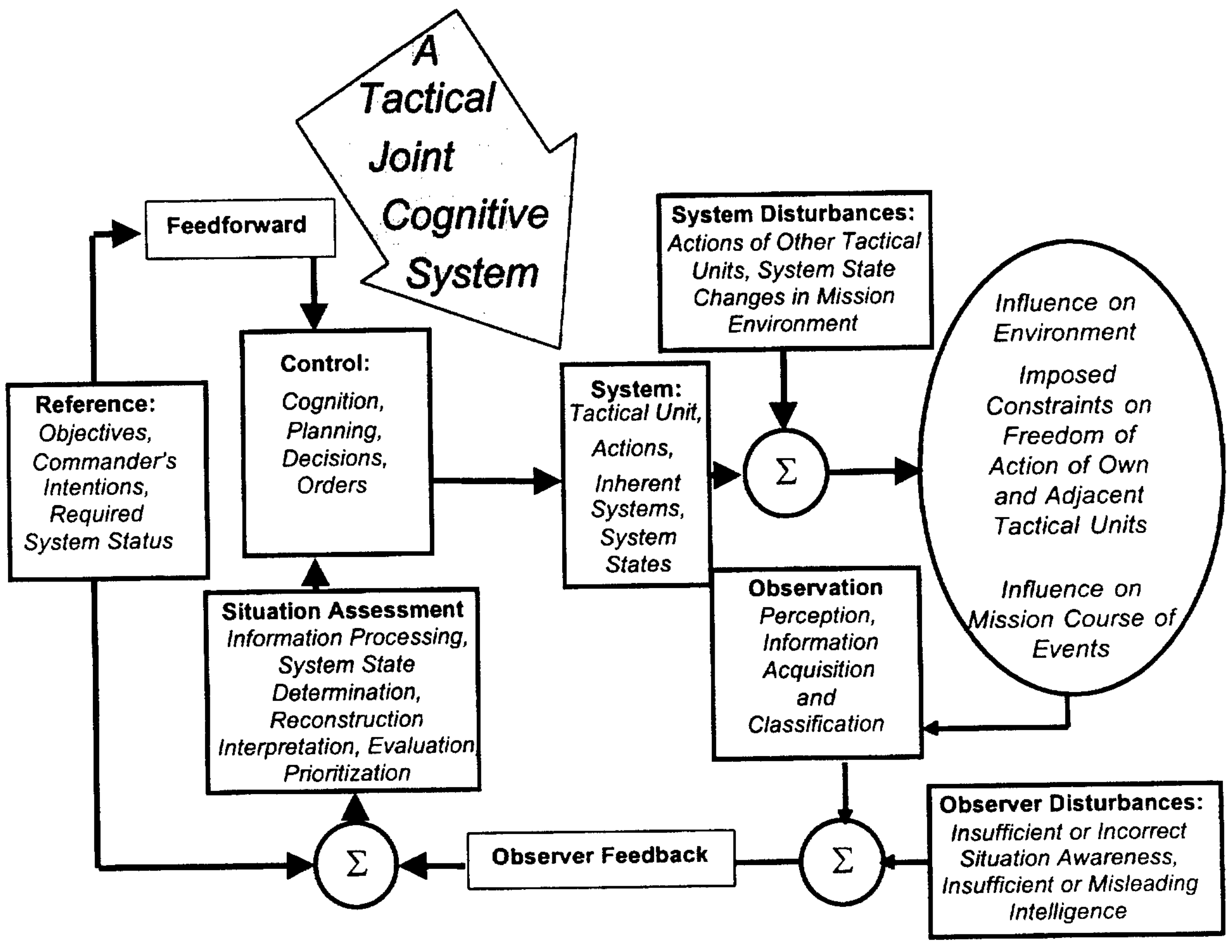

Figure 3. The mission model.

THE CONTEXTUAL CONTROL MODEL: CONTROL, COGNITION, AND CONTEXT

Until now, we have not been able to accurately describe the intricate mechanisms and processes of controlling a process like a tactical mission. The complex, situation-dependent properties of command and control in tactical missions are not easily identified, and hence, they are difficult to evaluate and improve. The need for building a conceptual framework for time-critical command and control of dynamic tasks in hazardous environments showed to be satisfactory met by the concepts of the cybernetics-influenced Contextual Control Model (COCOM) (Hollnagel, 1997).

BASIC PRINCIPLES OF CONTEXTUAL CONTROL

In CSE, cognition and control are always imbedded in a context. The context includes demands and resources, tasks, goals, organisation, and social and physical environments. When modelling cognitive processes, such as command, control, and intelligence processes, one must account for how cognition depends on the overall context rather on the input. Procedural prototype control models assume a characteristic sequence of actions, whose ordering is determined by the control prototype (Hollnagel, 1998).

Contextual control models, however, focus on how the choice of next action is determined mainly by the current context of the mission. Contextual control models describe action sequences as constructed rather than previously defined. The choice of action is controlled by the context, and actions can be both reactive and proactive. Contextual control models make a distinction between competence and control, in that competence describes what the operator and commander is able to do, and control describes how he achieves it.

MODELS AND MODES OF CONTROL

Control modes are theoretical constructs. Control will vary along a continuum instead of shifting between discrete modes. It is however important to make the main characteristics of different modes of control distinctly separable in order to observe, identify, and classify control The control mode characteristics of the Contextual Control Model is depicted in Table 1.

Table 1. COCOM Control Modes and Characteristics (Derived from Hollnagel, 1997; 1998).

Control Mode	Main Characteristics					
	Subjectively available time	Familiarity of situation	Level of attention	Number of goals	Choice of next action	Evaluation of outcome
Strategic	Abundant	Routine or novel	Medium - high	Several	Prediction based	Elaborate
Tactical (Attended)	Limited, but adequate	Routine, but not quite- or task is very important	Medium - high	Several, but limited	Plan based	Normal details
Tactical (Unattended)	More than adequate	Very familiar or routine- or almost boring	Low	Several, but limited	Association based	Perfunctory
Opportunistic	Short or inadequate	Vaguely familiar but not fully recognized	High	One or two (competing)	Association based	Concrete
Scrambled	Very limited	Situation not recognized	Full - hyperattention	One	Random	Rudimentary

COCOM Issues

Important model issues concerning the use and utility of the COCOM are:

- Transition between control modes. What causes control to change from one mode to another, whether it is lost or gained?
- Performance in a control mode. What is the characteristic performance for a given control model?
- Interaction between competence and control. Higher competence makes it more likely that control is maintained.

Results

The MEA results indicated that supporting individual and team situation awareness by means of systems theory in the execution of an operation would yield improved mission resource management and overall unit mission efficiency, and enhanced mission endurance of the units and systems engaged in the mission. When tested in initial method trials in the military command and control domain (Worm, 1998c), the contextual control framework proved to have the descriptive power necessary for this endeavour. Together with development of fast and accurate information processing systems and decision aids, CSE and COCOM will have positive impact on future studies of tactical mission command and control, and will most probably have affect on the outcome of actual tactical missions, if implemented appropriately. Future information processing systems for comprehensive, fast and accurate observation and registration of battlefield courses of action as well of the reasoning, decisions and actions of commanders, soldiers and other operators will benefit from an extensive implementation of the MEA, CSE and COCOM concepts. This will have a positive impact on future studies and implementations of tactical mission command and control.

Applications and Future Work

The work ahead in our research field will in brief consist of pursuing three main schemes concurrently in order to achieve tangible and evident results:

- Continued identification, modelling, and synthesis of joint tactical units, of tactical missions, and of C3I processes, by means of case studies, field studies, and experiments using a combined Control Theory and Cognitive Systems Engineering (CSE) framework.
- Identification and analysis of factors that cause limited or sub-optimal C3I performance, by investigating the need, flow, and processing of information and intelligence in military and other high-risk operations.
- Integration of various methods and tools for future innovative development and design of tactical systems, and training of tactical forces.

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A Command and Control Operational Architecture for Future Warfighters

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1. The role and importance of architectures

Command and control architectures provide the frameworks to design, develop, and build the C2 systems capable of greatly increasing the effectiveness of military forces. In the United States, there are three classes of architectures involved. These were developed by the US Army Science Board and accepted by the US Defense Science Board and are consistent with generally accepted architecture design criteria, namely, Technical Architecture (the equivalent of building standards), Systems Architecture (the systems engineering) and Operational Architecture (the operational concept and connectivities that determine how the system will be used). This paper focuses entirely on the Operational Architecture, and uses an analytical approach to decompose it in terms of concept, structure, connectivity and activity.

An Operational Architecture must satisfy the following four requirements:

- Identify Mission Objectives
- Identify Information Exchange Requirements
- Identify Logical Connectivities
- Identify Operational Elements

In this paper we project our thinking to envision what kind of C2 Operational Architecture will be required to support the goals of Joint Vision 2010. In the "Concept for Future Joint Operations–Expanding Joint Vision 2010's Ideas" the following quote is relevant: "From time to time in the course of military history, unique opportunities arise. If recognized and exploited correctly, these opportunities can provide a tremendous step forward in warfighting capabilities. This is particularly true when technological advancements are so significant that they present the opportunity for leap-ahead capabilities. When these capabilities are applied with the "right" operational concept and

organizational structure, the result is so profound as to produce a revolutionary change in the conduct of military operations."

Current and anticipated advances in information technology present such leap ahead opportunities. However, these advances by themselves do not necessarily increase military effectiveness. Rather, these technologies must be employed within appropriate operational organizations and concepts of operations. This paper presents an approach to a new operational architecture able to fully exploit anticipated technology advances. It reviews the current operational architecture, describing some of its limitations. It then extracts architecture principles required to overcome these limitations, presents an architecture which does so, and describes the increases in military effectiveness. Finally, a list of anticipated changes in DOTMLP (Doctrine, Organization, Training, Material, Leadership, and Personnel) required to support the architectural concepts are presented.

The architectural analysis is conducted from four different perspectives:

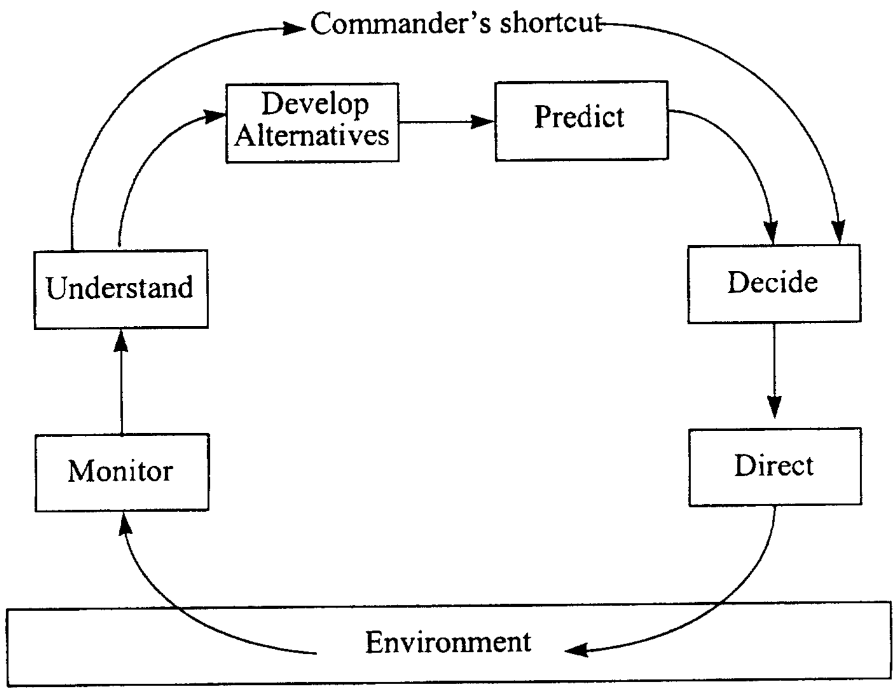
1. First, we look at the Operational Concept of the Command and Control Architecture. This requires several perspectives in itself to clearly depict its high degree of integration.
2. Second, we examine Command Relationships, as they exist today and will exist in 2010. These are displayed side by side to highlight and better explain the differences.
3. Likewise, we examine Node Connectivity as it is today and will become in 2010.
4. Next, we present Activity Models that capture the dynamic activities that take place in an operation, again in the context of today and 2010.

1.1 Traditional C2 Operational Concept.

Figure 1 depicts the traditional C2 functions and cycle in the HEAT (Headquarters Effectiveness Assessment Tool) format. HEAT was developed in the early 1980's to reflect the then-current doctrine. The concept has proven quite robust and other paradigms such as the OODA (Observe, Orient, Decide, Act) Loop are easily subsumed within it. The "Commander's shortcut" is a common occurrence in military operations. Commanders recognize that a familiar or anticipated situation lends itself to standard or

anticipated actions, and so choose to carry out those actions without an explicit formal planning. It should be noted at this point that speed of command is, in itself, not necessarily an unmitigated good. Rather, the quality and timeliness of decisions are what is really important. Thus, the OODA Loop premise that "acting inside an opponent's decision cycle will bring success," will not work if the decisions lack quality. Bad decisions—no matter how quickly made—are still bad decisions.

Figure 1. Traditional C2 Operational Concept & Cycle (HEAT)

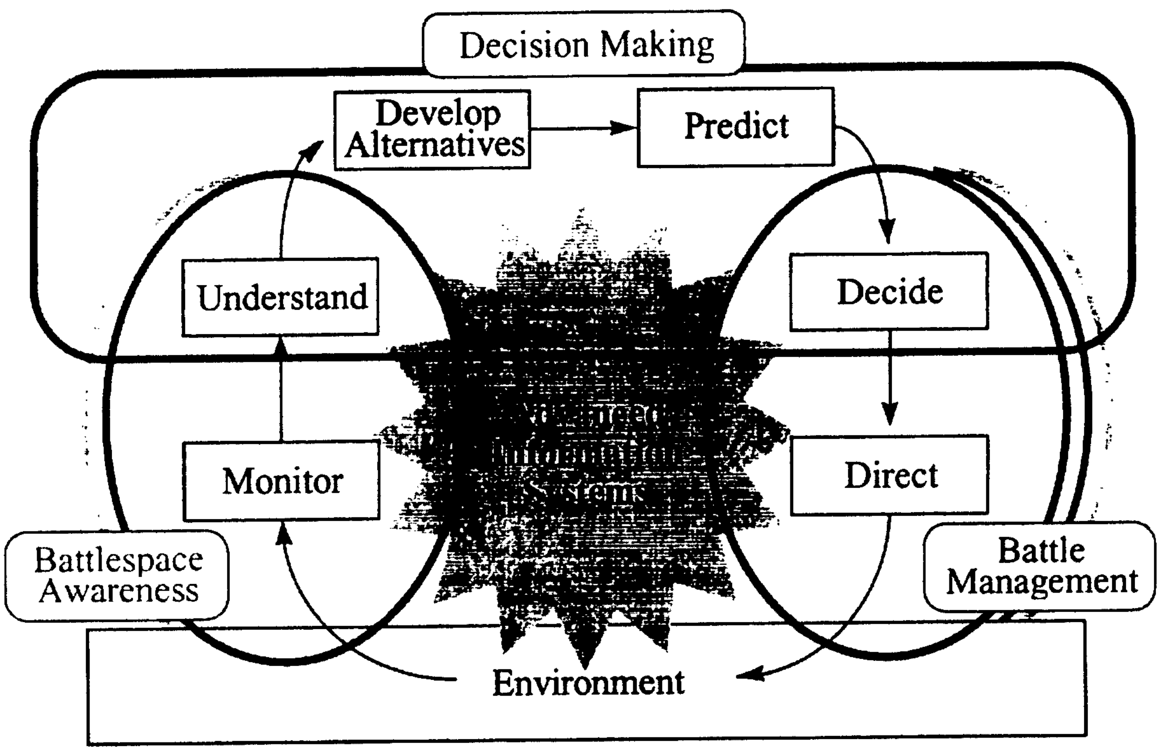


1.2 Command and Control Domains

Figure 2 shows how the basic C2 functions fit into three primary domains (Battlespace Awareness, Battlespace Management, and Decision Making). These must be tightly integrated if future command and control performance is to prevail over ever more competent and well equipped adversaries. The introduction of Advanced Information Systems has the effect of pulling the C2 domains closer together and enhancing the

performance of C2 systems that provide the understanding of the capabilities, status of equipage, and readiness to undertake specific missions. Central to this performance is the capability to provide a common, coherent, and accurate picture of the battlespace to all appropriate commanders and staff elements. While in the past battle-managers had an incomplete understanding and were always waiting for pieces of the picture, they can now share a common view. Further the richness of the shared information can alter the relationships between the domains.

Figure 2. Impact of Advanced Information Systems



1.3 Impact on Decision Making

When combined with extensive coverage of the order of battle of the opposing forces, faster than real time simulation of potential enemy courses of action, and exceptional high capacity communications, military commanders in 2010 will see the three domains pulled ever closer together. The outcome of this process should be a command and control system that bases its decisions and management actions on a bedrock of accurate and common understanding and acts (reacts also, but the initial responses of commanders that may be the most important could be those that are proactive) to make quality and timely decisions. Further, the quality of the information allows us to better parse the decision making process. **Simple Decisions** are those for which a stimulus or event requires a specific response. These are easily automated. **Contingencies** can be considered in advance and **Contingent Decisions** are those that require a response from a known list and can be categorized through "if-then" logic. These are also quite automatable. On the other hand, **Complex Decisions** are those in which the decision-maker must create the list and these are extremely difficult, if not impossible, to automate. Automatable support (e.g., M&S) can nevertheless assist the decision-maker in complex decision-making.

2. Overview of Operational Concept

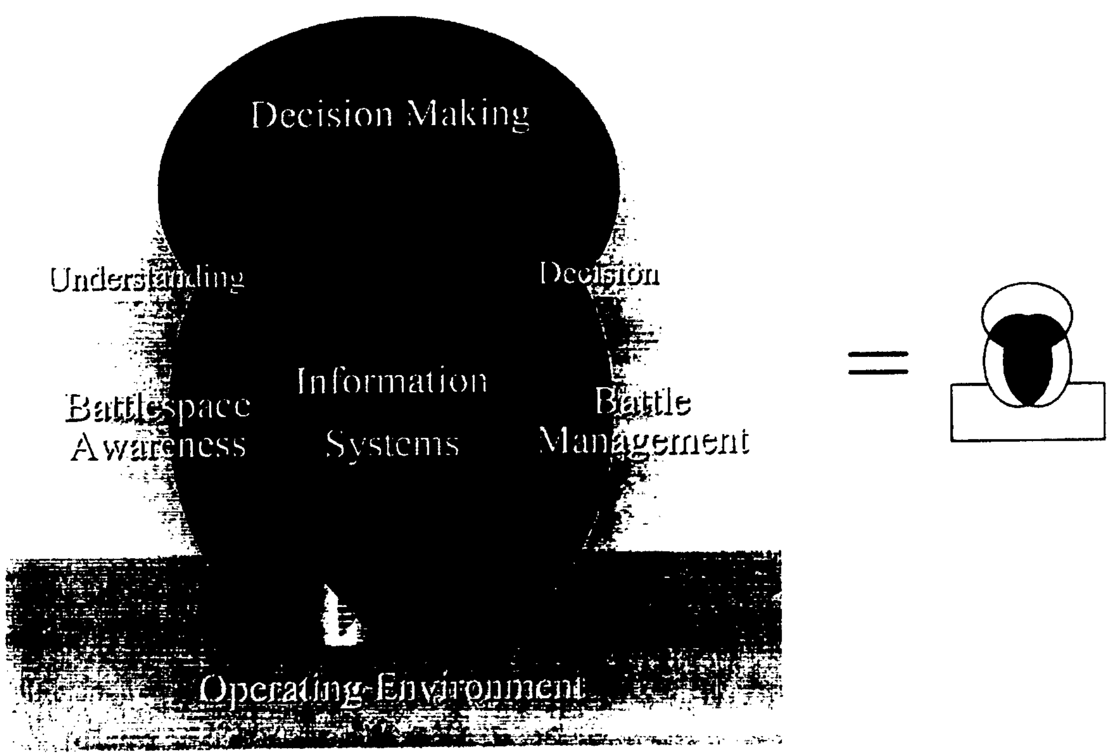
The goal of Full Spectrum Dominance as described in Joint Vision 2010 (JV2010) is achieved through much better Integration, Information-Enabled organizations, and use of Intelligent Control Systems. Better integration (both vertical—between command layers, and horizontal—across function and time) yields greater simultaneity. Information-Enabled organizations have a common shared view of the situation at all levels, and Intelligent Control Systems yield the ability to make rapid proactive plan adjustments in response to changing battlefield conditions.

As described earlier, the command and control process and its use of information has generally been viewed in terms of the C2 Cycle, OODA Loop, etc. Facts concerning the environment are collected, understandings of the situation are generated (Battlespace

Awareness), alternative courses of action are explored, a decision is made (Decision-Making) and disseminated to own forces for execution (Battle Management).

The advent of the information age enables this cycle to become much more efficient and much better able to support agile command and control and battle management. Figure 3 symbolizes a JV2010 Operational Concept of advanced information processing linking Battlespace Awareness, Decision Making, and Battle Management, where information becomes ubiquitously available to all processes simultaneously. As the information network matures, these processes are more fully coordinated and better able to support one another. This process is represented by the "snowman with a necktie" icon at the right side of the slide. It serves as a shorthand version that supports other depictions of the operational architecture.

Figure 3. Operational Concept: Full Spectrum Dominance through Integrated, Information-Enabled, Intelligent Control Systems

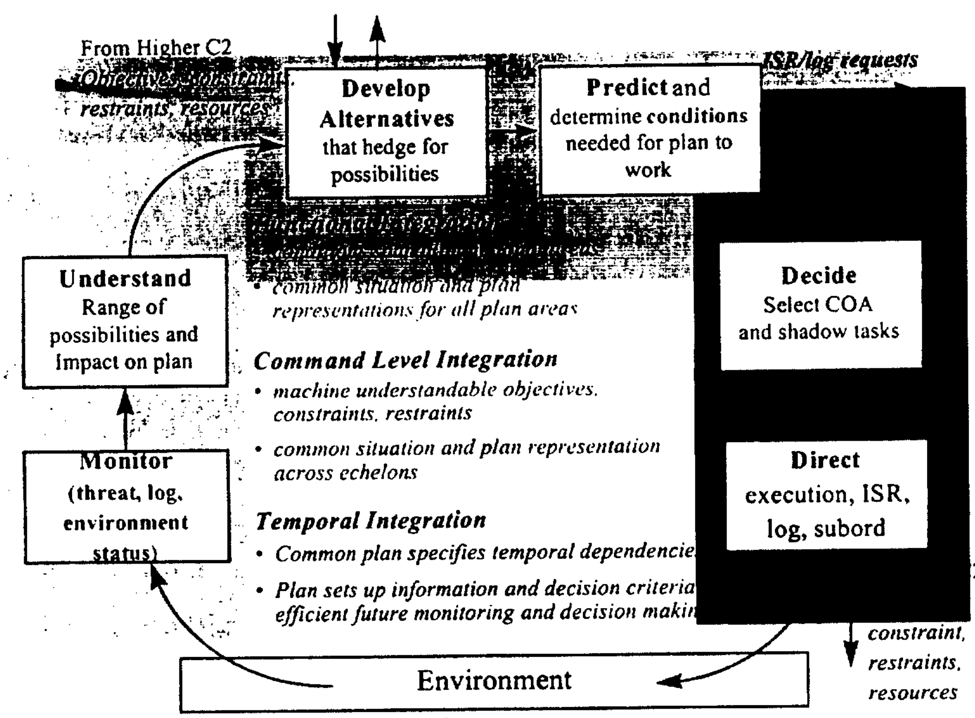


2.1 Operational Concept: Integrated Systems

Figure 4 shows the effects of integration. Operations are be better integrated across command echelons, across functional domains, over time, and with coalition partners. In a continuous planning and execution environment, better integration is supported by sharing machine-understandable common situation and plan representations that relate threat, environment, and logistics to specific plan tasks and objectives.

Functional Integration is supported through the task condition attributes in the Common Plan Representation. These conditions specify the required logistics, threat, environment, information, and own plan status required to execute a plan task. These conditions relate threat status, ISR, logistics, and weather directly to the needs of the plan, and hence to the achievement of the commander's objectives. Using this representation, information processing algorithms can estimate the importance of each logistics or ISR

Figure 4. Operational Concept: Integrated Systems



request to achieve the commander's objectives.

Command Level Integration increases "unity of command." It is supported by a common plan and situation representation available at all command levels, possibly supplemented by messages that computers can understand. Key plan information provided by the commander to subordinate units are objectives, constraints, resources, schedules and contingencies. Additional integration may be supported by including rationale and areas where constraint/restraint relaxation is possible.

Temporal Integration is also supported by these common representations, which can show the temporal and logical relationships among planned tasks and between successive states of an evolving situation. Continuous planning and execution integrates actions and objectives temporally. At each time, the continuous plan representation projects to the future to identify future plans and objectives at risk.

2.2 Operational Concept: Information Enabled

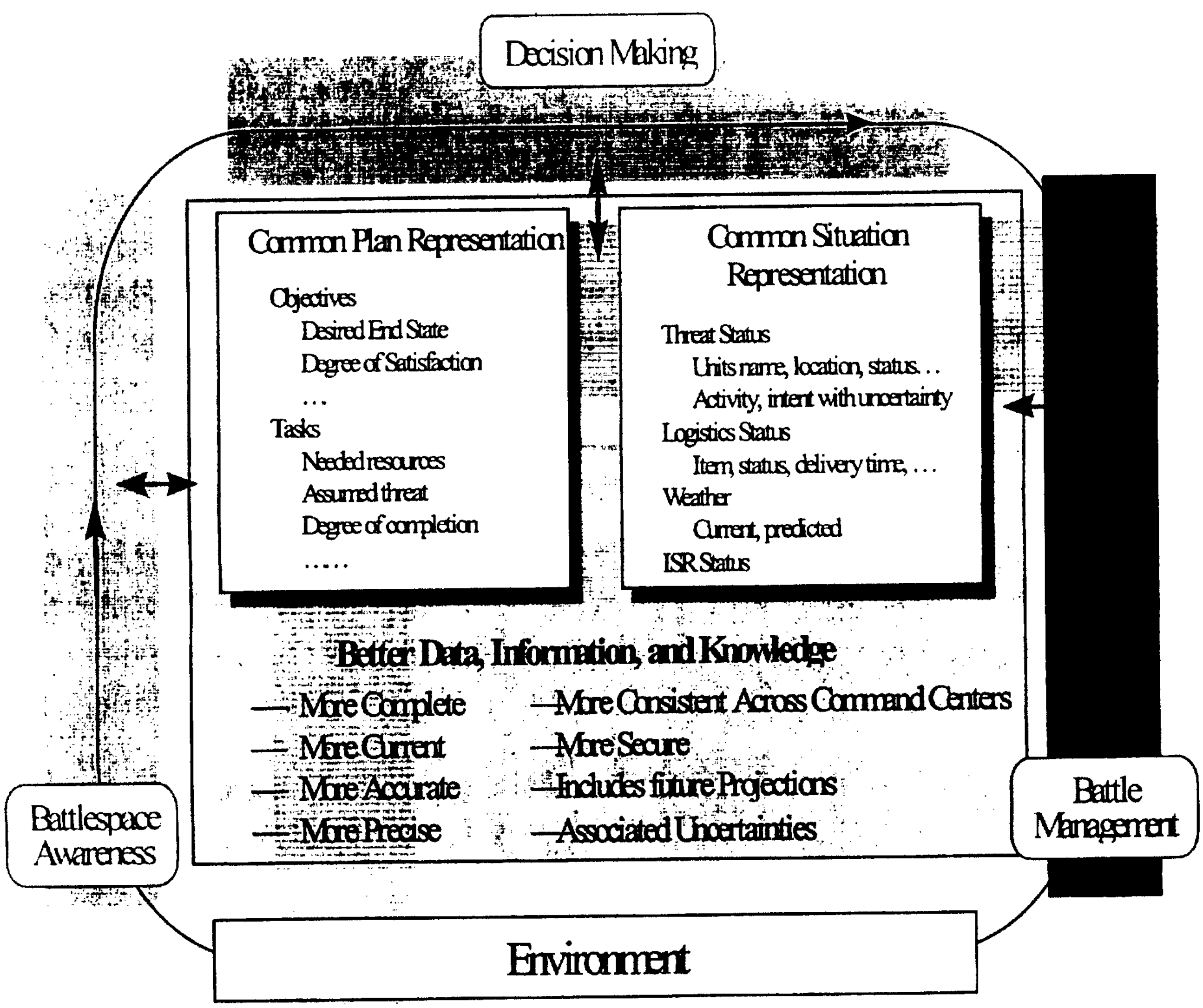
The ability to both distill and process better information, and simultaneously share that information through the integrated network is the key driver that enables the enormous gains in battlespace awareness. Better information is more complete, more consistent, more accurate, more precise, more consistent across command centers, and more secure. This improved battlespace awareness yields better knowledge and allows future projections of the battlespace, alternative futures, and associated uncertainties. As a result, decision-making and battle-management are also improved.

As seen in Figure 5, shared information includes Common Plan and Situation Representations, and contains the types of information shown. The Common Plan Representation specifies all plan objectives and tasks, contingent tasks, the units and organizations responsible for carrying out the task, times and locations at which tasks are to be carried out, explicit desired end states, and the conditions required for selected and contingent tasks to be successful. These conditions include required resources, threat status, weather, and information availability. The plan representation includes an

assessment of plan status, including future tasks and objectives at risk and rationale for that assessment.

The Common Situation describes the identity and locations of adversary forces, their status and capabilities, their Representation describes both the red and blue situations. It organization, possible activities, objectives, and the rationale for all assessments. The blue situation describes the locations and status of blue forces, logistics and ISR status. The Common Situation also provides information about neutrals and/or non-combatants, and about the environment.

Figure 5. Operational Concept: Information-Enabled Systems



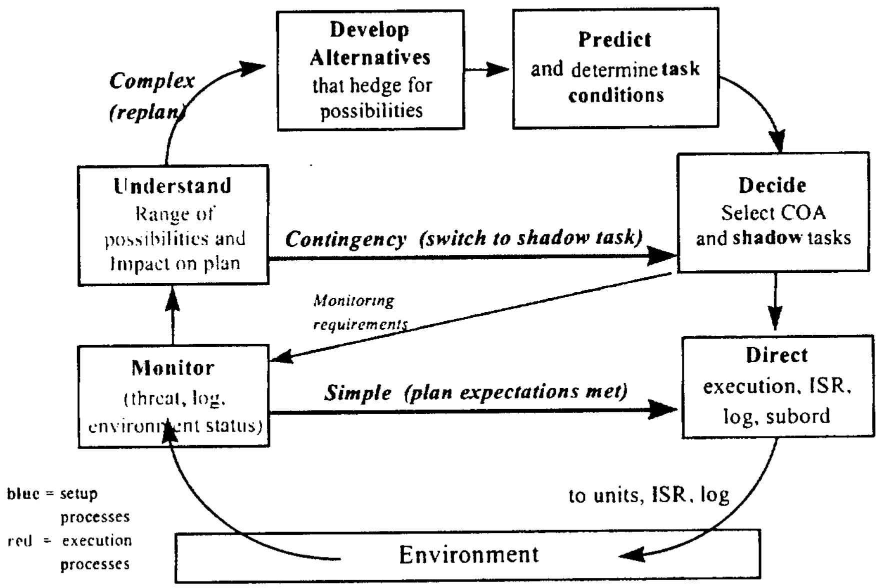
2.3 Operational Concept: Intelligent Control Systems

Control systems keep systems on course by comparing desired states with actual states, and by sending feedback correction signals to correct for deviations. They are required whenever systems must operate in complex changing environments which are too complex or chaotic to work by dead reckoning. They are essential in the conduct of military operations, and have always been employed in some form to support these operations. The "shoot-look-shoot" doctrine is a control system at work. A more complex example of intelligent control is an execution policy of identifying possible hostile actions, of finding a posture that will work should any of these actions arise, of monitoring the situation for earliest possible signs that the adversary will or will not exercise one of his possible actions, and of adjusting the posture in response to these signs.

The concept of Battle Management through the use of Intelligent Control Systems as seen in Figure 6, is partly enabled by sorting decisions into **Simple, Contingent**, and **Complex.** As described earlier, all three decision types are driven by situation data, and require monitoring the threat, logistics, ISR, and environmental situations.

Intelligent Control requires both set up (colored blue) and execution (colored red) procedures. The set up sets in place the information required for intelligent control. It defines the different contingencies and the situations under which each contingency is to be adopted. It also sets up the situation monitoring system. The execution systems that support intelligent control monitor the situation and assess the situation's impact on the plan. If the situation is evolving as expected, the intelligent control system permits the plan to proceed as originally formulated. If the situation matches one anticipated by one of the contingencies, the control system helps the commander switch to the appropriate contingency. If the situation requires replanning, intelligent control alerts the commander to this requirement.

Figure 6. Operational Concept: Intelligent Control Systems



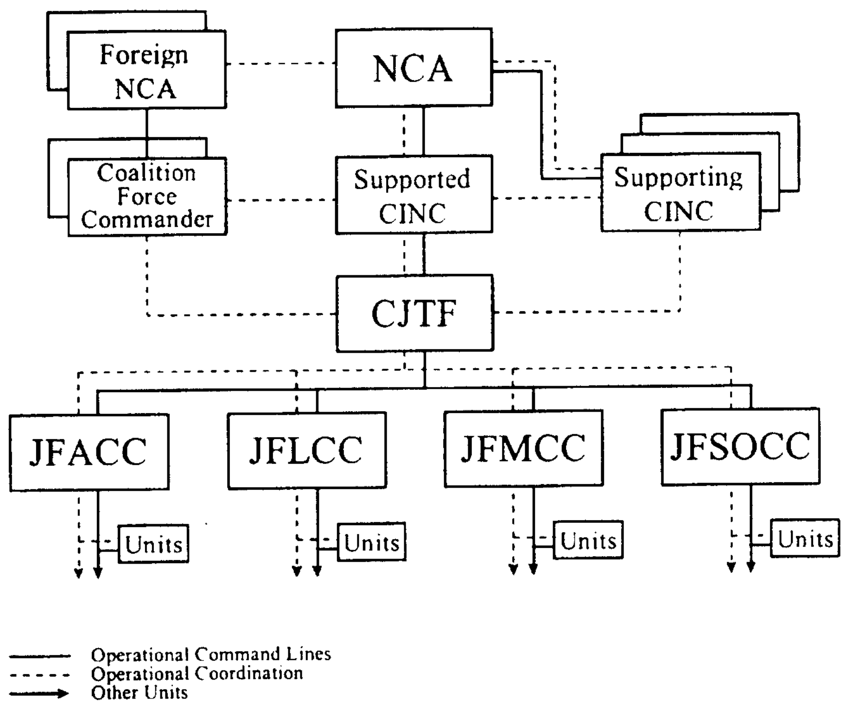
3. Joint Operational Command Relationships 1998.

The structure of joint operational command relationships central to the command and control of the Joint Task Force will change between today and 2010. The chief reasons for the change are to simplify command and control, to tailor the forces picked for a given mission, to enhance the organization's agility, and to meet the challenges of achieving dominance over the battle space. To understand the magnitude and impact of these changes, Figures 7 and 8 depict a comparison of the 1998 and forecast 2010 structures.

In today's structure the forces assigned to operational missions are grouped regardless of parent service, in operational-domain-focused components. The component commander has operational command over and plans the actions of his assigned units. Execution of the component commander's orders takes place within the structure of the service of the unit, starting usually at the closest major command center above the unit. To carry out a joint operation at least some portion of each of the four component staffs and the

individual commanders would take part. In addition to the command lines linking the component commanders, informal coordination takes place between components and their commanders and staffs.

Figure 7 Joint Operational Command Relationships
1998



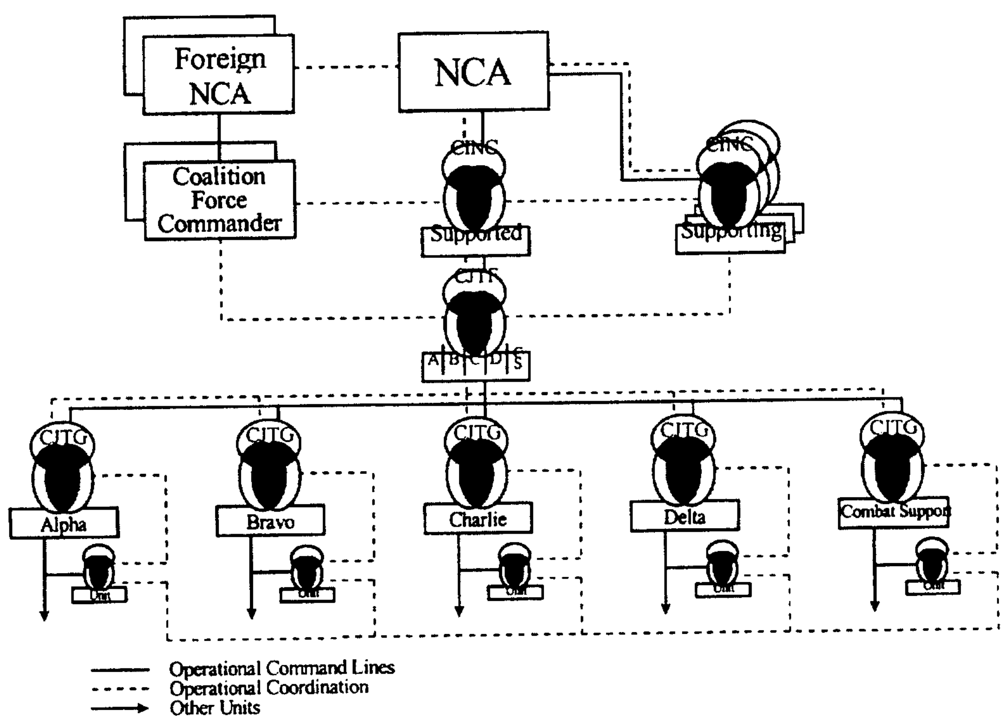
3.1 Joint Operational Command Relationships 2010

In 2010 the CJTF will consist of service-provided, appropriately selected and sized elements integrated into Joint Task Groups (JTGs). These will be task-specific and functionally oriented. Command and control will be integrated across functional elements and across command echelons. The conversion of many of the decisions previously deemed "complex," into simple or automatable decisions and the elimination of the requirement for layers of command that filter and repackage information for higher levels, will push responsibility downwards, flattening the organizational structure. Each

JTG is envisioned as a dynamic organization, created on the basis of the mission assigned and the forces available. The dynamic nature of the task group structure comes into play as the mission changes. Most changes at this level will likely be self-directed. That is, the units involved will reorganize based on their perception of the tactical situation and the current doctrine.

JTGs will be mission specific, and appropriately trained and equipped. They will be supported by JTG-Combat Support which will conduct those missions that range all across the AOR and JTF assigned tasks. These include Intelligence, Information Warfare (IW), air and Theater Ballistic Missile (TBM) defense, space and other support services such as supply transportation from in-theater depots of ports to the units. To coordinate JTG direction and support requests, each JTG has a CJTF headquarters support staff element assigned specifically to the CJTG to work within the JTF for integrating in-theater and CONUS support.

Figure 8. Joint Operational Command Relationships
2010



In summary, the command relationships will be transformed through a fully capable, automated and integrated command and control system. There will be a common network and common support. No longer dominated by service or arena of action, the forces will be task dominated and inherently agile.

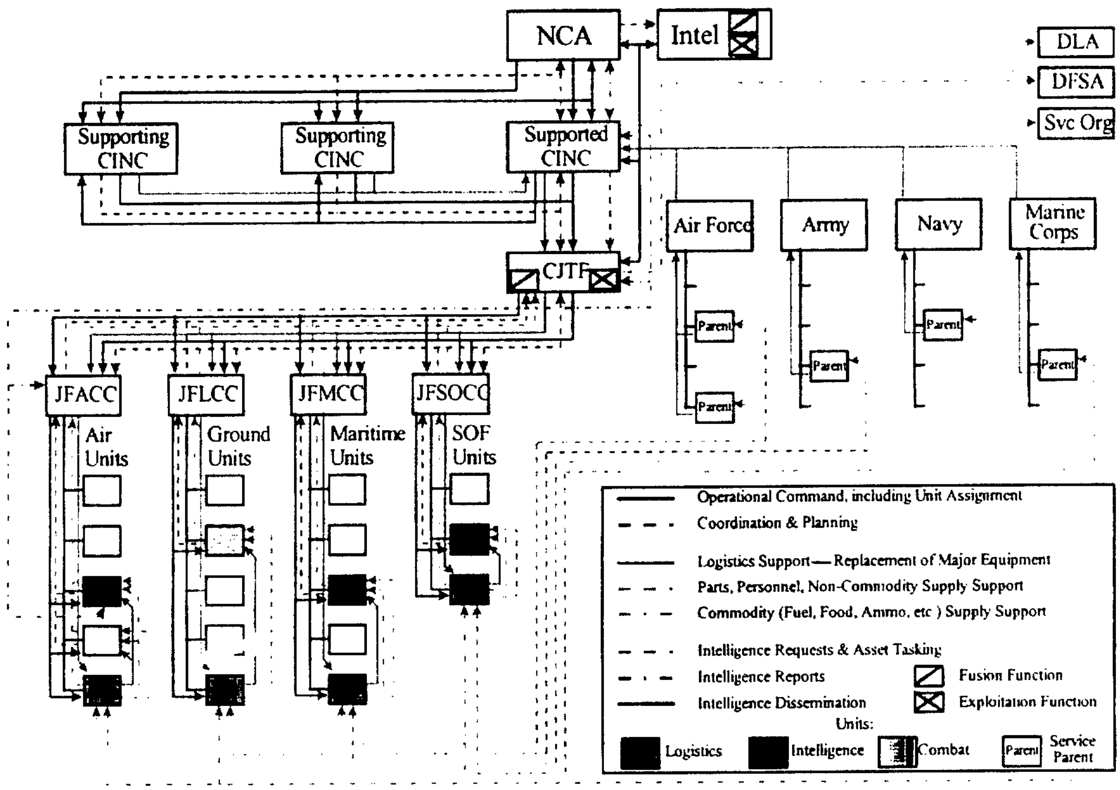
4. Joint Operational Connectivity Relationships 1998

At the present time node connectivity between command levels and across most component commanders is different for operations, intelligence, and logistics. In most cases it can be characterized as "stovepipe." Operational command and control is hierarchical and tends to be rigidly structured although numerous informal feedback loops exist.

Intelligence in particular tends to flow down stovepipes with most fusion and exploitation occurring at the CJTF and higher levels.

The logistics connectivity is the most complex. In the United States, each service is responsible for logistics support of its components in the JTF. Major equipment end items are replaced by the parent service through the supporting CINC(s) to the supported CINC and then to the component via the CJTF. Parts, personnel and non-commodity support flow from the service parent directly to the components, while commodity support such as fuel and ammo comes from various US Defense Agencies and flows directly to the components as well.

Figure 9. Joint Operational Connectivity Relationships: 1998



4.1 Joint Operational Connectivity Relationships 2010

Under US law the individual Services are responsible to organize, train, and equip their own forces. It is unlikely that this law will disappear or be significantly changed in 2010, but connectivity between command and control system nodes will undergo major changes in both form and substance as information superiority systems come into operational service. Present stovepipe lines of command and control between the CJTF, the CINC who oversees his operation, along with other JTFs under his command, and the units of the forces under his command will be replaced. First of all, the units under command of the CJTF will change from component command forces to multi-service joint task groups, composed of units selected for their contribution to the operation. Second, the capability of the information superiority systems will be such as to provide the commander with nearly complete understanding of all present and projected actions by

his allies and his enemies. Unit-to-unit coordination and mutual support for the benefit of the task group will be provided with command nodes and linkages to expedite the process. As operations will be undertaken by multi-service task groups the processes of command decision will be speeded immensely. Intelligence and logistics support will be greatly facilitated through the use of "anchor desks" at the Task Unit, CJTF, and CINC levels.

Figure 10. Joint Operational Connectivity Relationships: 2010

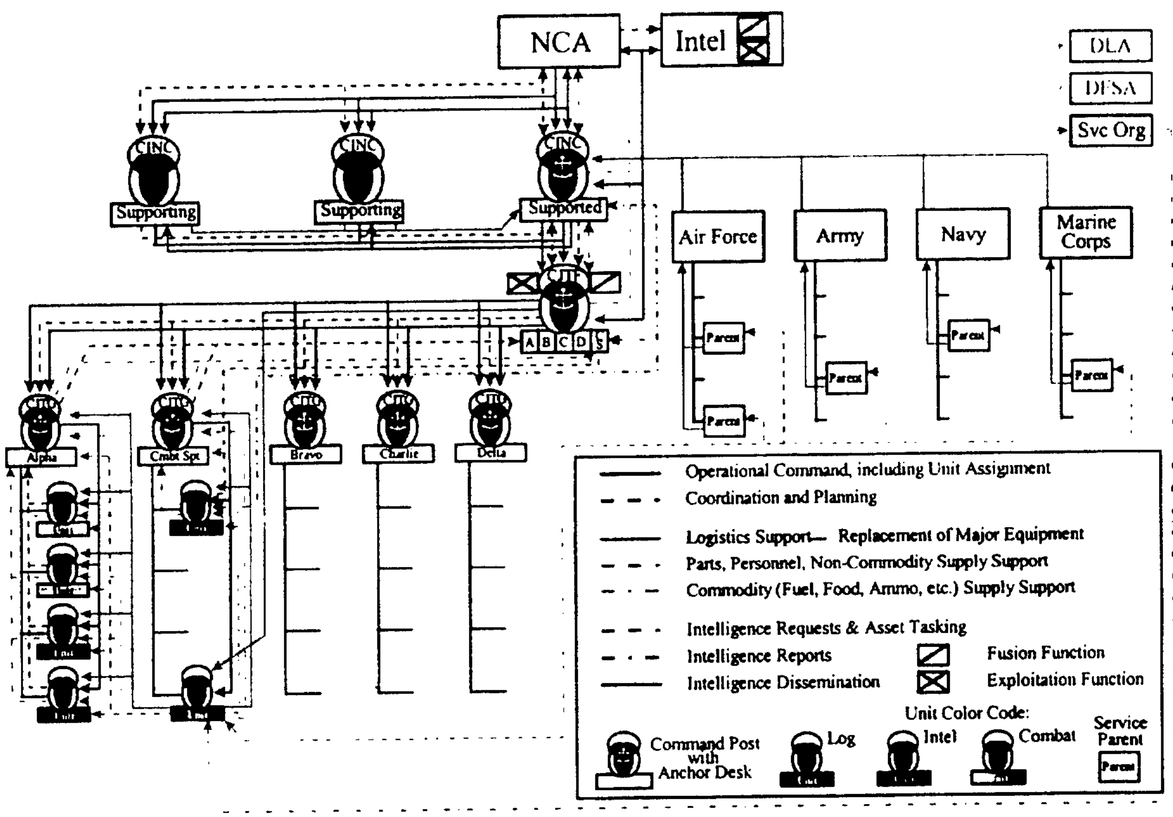
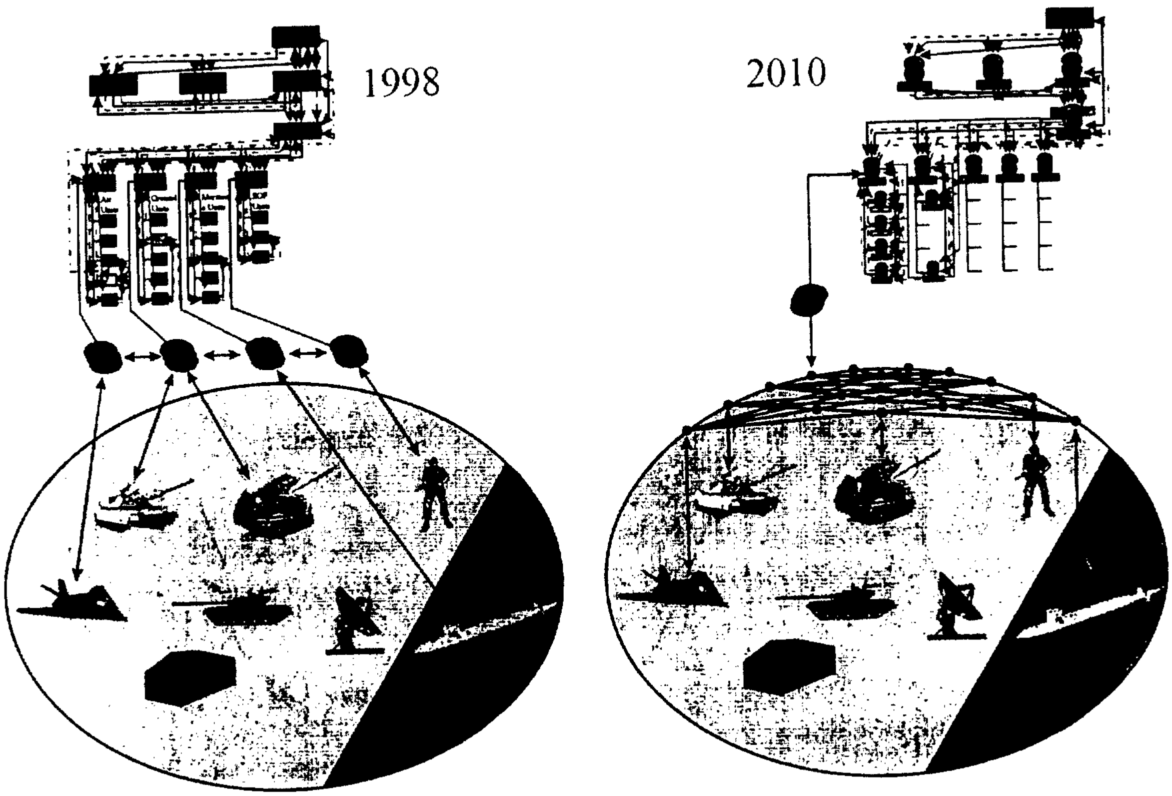


Figure 11. JTF Operational Activity Models



5. Operational Activity Models

The Biggest pay off from this Operational Architecture concept occurs in Operational Activity. The confusing multiplicity of stove pipe C2 systems is replaced by a ubiquitous C2 grid or network that enhances coordinated action and the ability to optimize decision quality and timeliness. The benefits also include more efficient employment of resources (the right weapon on the right target), and a greatly reduced likelihood of blue on blue fratricide.

6. What is the IMPACT?

Information technology improvements by themselves will only result in marginal improvements and not achieve the goals of JV2010. That is why the operational architecture is so important: because it gives structure and control to best exploit the new capabilities. But, in addition, changes in the DOTMLP (Doctrine, Organization, Training, Material, Leadership, and Personnel) must also occur to create truly revolutionary change. These changes are depicted in Table 1.

Table 1. Operational Architecture Impacts

Old System	New System
•**Doctrine**: —Decision Process Cyclical. —Decisions top down; Reports bottom up. —Information is concentrated in a few areas; fusion is slow/ manual; information is often fragmented/incomplete. —Planning: Highly structured; slow to respond.	• Decisions made where appropriate/units self adjust/ make changes on the fly. • Information ubiquitous/available at all levels at desired degree of detail. • Continuous, integrated planning and execution
• **Organization:** -Hierarchical. -Communications move through multiple stovepipes. -Main Headquarters non-mobile with large staffs clustered around the commander	• Organization flatter and vertically integrated. • Integrated communications network (horizontal and vertical). • Small, mobile HQ supported by virtual, distributed staff.
• **Training**: -Emphasis on specialty skills (e.g., Intel, Log, Comm).	-Emphasis on ability to access data and use fusion engines.

• **Material**: -Information Systems overlaid on JOPES process. -Ponderous acquisition process.	• Integrated Information Systems, Sensors, and Communications Equipment. • Streamlined acquisition process
•**Leadership**: —Chain of Command	• Orchestration/ high level management by exception.
•**People**: —Large number of specialists working on details to build the big picture.	• Small numbers of generalists working high levels of visualization with "Drilldown" access to details.

7. Conclusion

The C2 Operational Architecture for the future offers the potential to leverage Information Technology advances for a dramatic increase in military effectiveness. The promise will happen only if farsighted military and civilian leaders are willing and able to adapt to new ways of doing business.

Quality Criteria for User/System Interfaces

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ABSTRACT

User/system interfaces are essential components of any interactive software, including command and control software. As part of overall quality of any interactive software quality issues of interfaces are very important. A set of 27 interface quality criteria for user/system interfaces are presented in four groups which are convenience (usability), communicativeness, reliability and evolvability. The *convenience* criteria are related with: conveniences of the language, terminology, metaphor and the inputs; and functionality, simplicity, consistency, minimum memory load, navigability and least training. *Communicativeness* criteria cover: informativeness, guidance, perceptiveness, explanation ability, expressiveness, esthetic/cultural acceptance and types of user/system relationship. *Reliability* criteria are concerned with: error prevention, error tolerance, caution, predictability and access reliability. *Evolvability* criteria cover: adaptability, customizability, learning ability, maintainability and portability. The criteria can be used for evaluation and comparison of existing interfaces as well as for the design and implementation of new ones. Four tables with appropriate questions are provided to systematize the evaluations.

1. USER SYSTEM INTERFACES

1.1 INTRODUCTION

User/system interfaces are important components of all software systems (Galitz, 1996). One can consider user/system interfaces from several points of view: Goodwin (1989) presents interface issues for C programmers. Marcus (1992) presents detailed descriptions and comparisons of Macintosh, Nextstep, Open Look, Motif system, Microsoft Windows, and OS/2 Presentation Manager. Moreover, he provides a comparative product-specific terminology used in the systems listed above. Molich and Nielsen (1990) concentrate on the essence of the user/system interface design problem and provide a list of suggestions for good designs. Horton (1990) considers design and implementation of on-line documentation and provides answers to the fundamental questions such as "what makes a good dialog?" Lee (1993) concentrates on object-oriented graphical user interfaces. In the late 1990s, functionalities and appearances of Internet interfaces are of importance. The Internet brought also new dimensions in interfaces such as Internet ethics (Cheong 1996). Sullivan and Tyler (1991) explore intelligent user interfaces. This topic is maturing both in the applications of agent technology as well as interactive voice technology to user/system interfaces (IUI '93, IUI '97, IUI '98, and IUI '99) and will necessitate refinement of the quality criteria for user/system interfaces.

An interactive software can be considered in two parts: a solution engine and a user/system interface (Figure 1).

The solution engine part is used to process the input and to produce solutions for given problems.

The user/system interface is used to communicate with a user in interactive systems. The user/system interface can be divided into two sections: A front-end interface and a back-end interface.

The front-end interface is used to enter inputs.

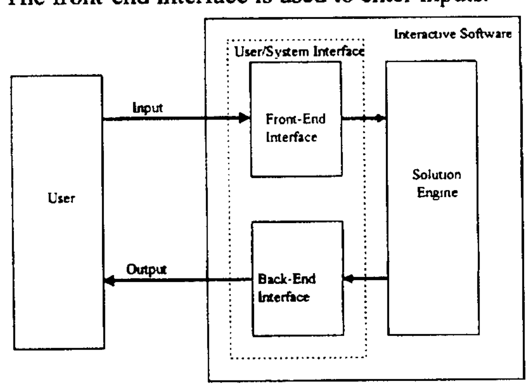

Figure 1. The elements of an interactive software

The back-end interface is used to get, process, and/or display outputs produced in the solution engine. For example, the back-end interface can display the data which is produced by the solution engine in graphic format for virtual or augmented reality applications.

1.2 THE NECESSITY OF USER/SYSTEM INTERFACE CRITERIA

The term user-friendliness is overloaded in referring to desirable aspects of user/system interfaces. Implementers, vendors and users of software tools and environments need a set of well-defined quality criteria for user/system interfaces. The criteria can be used to design and implement good interfaces as well as to evaluate, compare, and/or provide a basis to improve existing ones. Furthermore, a set of well-defined quality criteria allows one to choose explicitly the characteristics of interfaces that one would like to have.

2. QUALITY CRITERIA FOR USER/SYSTEM INTERFACES

Twenty seven quality criteria are identified for user/system interfaces. They are grouped in four areas, namely, convenience (or usability), communicativeness, reliability and evolvability.

2.1 CONVENIENCE (USABILITY) CRITERIA

Some advantages of satisfying convenience or usability criteria are as follows:

- Users can use the computer (or more specifically, the software) without needing additional documentation.
- Necessary information can be displayed on the screen when needed. In this way the memory load of the user can be minimized.
- Definitions of problems and evaluations the results can be done easily.
- Users can use the terminology of the application area.

The convenience criteria are listed in the sequel:

1. Convenience of the language (1.1)
2. Convenience of the terminology (1.2)
3. Convenience of the metaphor (1.3)
4. Convenience of the inputs (1.4)
5. Functionality (1.5)
6. Simplicity (1.6)
7. Consistency (1.7)
8. Minimum memory load (1.8)
9. Navigability (1.9)
10. Least training (1.10)

2.1.1 Convenience of the language (1.1)

The natural language used in an interface should ideally be the native language of a user or at least it should not hinder the proper use of the software.

2.1.2 Convenience of the Terminology (1.2)

An interface should be based on the application domain's terminology. The terms should not be confusing.

2.1.3 Convenience of the Metaphor (1.3)

The interface metaphor should be most appropriate (i.e., natural) to the application domain. Examples: desktop, book, index, card, form, calendar, agenda, instrument panel, warning or traffic lights, map, office, supermarket and layout (factory, theater, airplane). A door is an example of a 3-D metaphor in virtual reality.

2.1.4 Convenience of the Inputs (1.4)

An interface should to able to accept the types of inputs most appropriate (i.e., natural) for the application. Examples (conventional): keyboards, pointing devices (mouse, lightpen, trackball, joystick), touch screens, touch pens. Examples (relatively new types): handwriting, dataglove, deictic input (gestures), haptic inputs (touch, pressure), eye gaze tracking, speech or voice, and multimodal input.

Deictic inputs provide flexibility in virtual and/or augmented reality. Eye gaze tracking is important in civilian as well as defense applications. Interactive voice technology, once more mature, can be the basis for applications and/or operating systems based on speech; thus allowing voice commands.

2.1.5 Functionality (1.5)

An interface should offer complete set of abilities to specify problems and to process, analyze, and present results. Therefore, the input functionalities can be as advanced as the computer-aided problem solving environments. The output functionalities can be graphically oriented as it is the case of virtual or augmented realities; they can also include statistical or reasoning abilities.

2.1.6 Simplicity (1.6)

An interface should not have unnecessary and distracting information. The displays should be as uniform as possible.

2.1.7 Consistency (1.7)

There should be no ambiguity to initiate an action in different parts of the interface.

2.1.8 Minimum Memory Load (1.8)

Users should not be obliged to remember information from one part of the interface to another. Users should not be obliged to memorize the instructions. Instructions to use the system should be visible (for example, through icons or pull down or pop up menus). If there is a sequence of activities to perform a task, they should be performed for the user or at least the sequence should be made clear to the user. For complex and/or routine

tasks, software agents can and should be used to alleviate the workload of the user (Bradshaw, 1997).

2.1.9 Navigability (1.9)

Activities should be initiated as directly as possible. Navigation should be done with least movements. At every state of the system, the user should know: how to cancel the current activity and how to exit the system as well as how to initiate necessary activities.

2.1.10 Least Training (1.10)

An interface should require least amount of training. Any needed training should be available as just-in-time learning facility. It is highly desirable to have a self-pace demo on the utilization of the system.

2.2 COMMUNICATIVENESS CRITERIA

Some advantages of satisfying communicativeness criteria are as follows:

- The functions of programs can be visualized.
- Users can obtain information about the software system directly from the system.
- The software systems can support different types of users.

The communicativeness criteria are listed in the sequel:

1. Informativeness (2.1)
2. Guidance (2.2)
3. Perceptiveness (2.3)
4. Explanation ability (2.4)
5. Expressiveness (2.5)
6. Esthetic/cultural acceptance (2.6)
7. Types of relationship (2.7)

2.2.1 Informativeness (2.1)

An advanced interface can and should be able to prompt several types of knowledge which may (or should) exist in the system:

- Knowledge that the interface is incrementally receiving from the user and/or other knowledge which exist in the system, (including a user profile that the system should, maintain.
- Knowledge that the interface (should be able to), deduce from the knowledge provided by the user.
- Knowledge about the methodology on which the system is based on (e.g., simulation methodology).
- Fundamental scientific and engineering knowledge.

This may necessitate agents or mobile agents directly accessing to the appropriate sources of knowledge (by on-line payment of a fee, if necessary).

- Knowledge about the application domain (defense, business, etc.).

Comments similar to the one given for the previous topic is also applicable here.

- Knowledge about the software system and how to use it (e.g., annotation of icons upon focus).

2.2.2 Guidance (2.2)

An interface should be able to guide the user in solving problems by providing:

- Alternatives,
- Examples (demonstrations), and
- Sample data (with the possibility to modify and save them).

2.2.3 Perceptiveness (2.3)

An interface should be able to observe the user:

- To perceive the intentions of the user
- To decide when to initiate an advice.

This features are implementable by software agents (Bradshaw, 1997).

2.2.4 Explanation Ability (2.4)

A back-end interface should be able:

- To provide explanations/justifications of the decisions taken by the system, and
- To explain the results or the solutions recommended by the system

This features are basically implementable by artificial intelligence techniques.

2.2.5 Expressiveness (2.5)

An interface should be able to provide necessary output modes warranted by an application. Examples: direct feeding of actuator devices, voice annotation, on-line video help, multimedia outputs where text, picture (from files or rendered), animations, and video may co-exist.

2.2.6 Esthetic/Cultural Acceptance (2.6)

Shape, size, location, color, and movement of displayed objects; sound of audio signals and messages; and their relations to other objects should be consistent with universal (as well as local) cultural and esthetic norms.

2.2.7 Types of Relationship (2.7)

Patronizing, informal, and insulting tone should not be used. Human-like entities (including avatars) should be used when warranted and not just as technological curiosities.

2.3 RELIABILITY CRITERIA

Some advantages of satisfying reliability criteria are as follows:

- Possibility of preventing some types of errors in new programs and
- The avoidance of some types of errors of legacy (existing) programs.

The reliability criteria are listed in the sequel:

1. Error prevention (3.1)
2. Error tolerance (3.2)
3. Caution (3.3)
4. Predictability (3.4)
5. Access reliability (3.5)

2.3.1 Error Prevention (3.1)

A front-end interface should screen the inputs to prevent errors.

A back-end interface should filter the outputs to intercept unacceptable (and possible dangerous) outputs. For example, regardless how the software is implemented in a radiation therapy device (e.g., Therac), lethal radiation dosage can easily be avoided by an appropriate feature of the back-end interface.

2.3.2 Error Tolerance (3.2)

A front-end interface should tolerate errors (with confirmation):

- In case of erroneous activation of a task, the user should be able to exit without any side effect.
- An interface should encourage trial-and-error learning without causing frustration.

2.3.3 Caution (3.3)

An interface should:

- Confirm irreversible actions and
- Include an undo command (preferably several levels)

2.3.4 Predictability (3.4)

An interface should do what its users would expect it to do.

2.3.5 Access Reliability (3.5)

An interface should be able to monitor access to the system and report it.

This feature should be in addition to appropriate detection tools of viruses and trojans and fire walls (Scientific American, 1998).

2.4 EVOLVABILITY CRITERIA

Some advantages of satisfying evolvability criteria are as follows:

- A good interface can be changed easily; hence its maintenance is easy.
- A good interface can be adapted to the needs of a user.

The evolvability criteria are listed in the sequel:

1. Adaptability (4.1)
2. Customizability (4.2)
3. Learning ability (4.3)
4. Maintainability (4.4)
5. Portability (4.5)

2.4.1 Adaptability (4.1)

An interface should provide information needed by different categories of users such as: experts, transfer users, occasional users, and novices.

2.4.2 Customizability (4.2)

One should be able to easily tailor an interface to suit different:

- Nationalities and/or
- Preferences (for example, tailoring toolbars).

The natural language used in the interface should be easily and correctly understood by users. This may require multilingual abilities in an interface.

2.4.3 Learning Ability (4.3)

An interface should be able to remember the usage of the system by a user and should provide the relevant knowledge to enhance problem solving abilities of the user.

2.4.4 Maintainability (4.4)

The maintenance of the interface should be easy.

2.4.5 Portability (4.5)

A good interface should be portable to different platforms.

3. A SYSTEMATIC APPROACH FOR EVALUATION AND DESIGN

To ease evaluation of a current interface a systematic approach is used; for this purpose, one needs a table of questions (i.e., an assessment table) for each of the four areas, namely for convenience (usability), communicativeness, reliability and evolvability. Tables 1-4 are supplied as the assessment tables with referances to these four groups of criteria.

For each criterion, there is at least one question. For each question, the answer may be either yes (a desirable feature) or no. In the case of lack of a desirable feature, there are three possibilities according to the severity of the feature: (1) the interface is still acceptable, (2) the interface should be improved and (3) the interface should be rejected. Additional comment area can be used for specific information.

4. CONCLUSION

As important components of any software system, interfaces require particular care. Therefore, evaluations of user/system interfaces are of paramount importance. To be able to perform the needed assessments in an objective way, a set of criteria and a systematic approach is offered. The same criteria can be used as a basis for proper design of new interfaces or to improve existing ones.

This study can be enhanced in the following ways:

1. Enhance (add, delete, modify, annotate) the quality criteria.
2. Suggest better grouping for the quality criteria.
3. Enhance (add, delete, modify, annotate) the questions in the evaluation tables.
4. Develop a software for the quality assessment of user/system interfaces.
5. Take into account any feedback that may come from the readers.

5. ACKNOWLEDMENT

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Table 1. Convenience (usability) criteria for user/system interfaces

	Criteria		Questions	Yes	No: Accept	No: Improve	No: Reject	Comments
1.1	Convenience of the language	1	Is the natural language used in the interface, easy to understand for the users of the system? (e.g., is it the native language of the users?)					
1.2	Convenience of the terminology	1	Does the interface use the terminology of the application area?					
		2	Is the terminology used in the interface clear?					
1.3	Convenience of the metaphor	1	Is the metaphor appropriate for the application?					
1.4	Convenience of the inputs	1	Are the inputs appropriate for the application?					
1.5	Functionality	1	Does the interface offer necessary abilities to specify problems?					
		2	Does the interface have capabilities to process, analyze and present results in a manner required by the problem?					
1.6	Simplicity	1	Is the interface free from unnecessary or redundant information?					
1.7	Consistency	1	Is it easy to initiate/terminate an action in different parts of the interface?					
		2	Are these initiations/terminations specified in different places of the interface in a consistent way?					
1.8	Minimum memory load	1	Does the interface avoid referral of information between screens?					
		2	Can users solve problems without memorizing the sequence of steps?					
1.9	Navigability	1	Can one activate the actions as directly as possible?					
		2	Can one navigate with minimum movements?					
		3	Is it clear to the users how to exit from the current operations?					
1.10	Least training	1	Can one learn how to use the system with a minimal training?					
		2	Does the interface offer just-in-time learning facilities?					
		3	Does the interface offer a self-paced demo on how to use the system facilities?					

Table 2. Communicativeness criteria for user/system interfaces

	Criteria		Questions	Yes	No: Accept	No: Improve	No: Reject	Comments
2.1	Informativeness	1	Can the interface display (when needed) knowledge incrementally provided by a user?					
		2	Can the interface display knowledge deduced from the knowledge provided by a user?					
		3	Can the interface display knowledge about the methodology used in solving a problem?					
		4	Can the interface display fundamental scientific and engineering knowledge?					
		5	Can the interface give knowledge about application domain?					
		6	Can the interface display knowledge about the software system and how to use it?					
2.2	Guidance	1	Is the interface able to guide the user for solving problems?					
		2	Can it give examples when solving any problem?					
		3	Can the interface provide sample data (with the possibility to modify and save them)?					
2.3	Perceptiveness	1	Is the interface perceptive what users want to do?					
		2	Can the interface determine whether users need help or not?					
2.4	Explanation ability	1	Can the interface explain the decisions taken by the system?					
		2	Can the interface explain the results or the solutions generated by the system?					
2.5	Expressiveness	1	Is the interface able to provide necessary output modes that are warranted by an application?					
2.6	Esthetic/cultural acceptance	1	Do the elements of the interface consistent with universal (as well as local) cultural and esthetic norms?					
2.7	Types of relationship	1	Is the type of relationship with users free of patronizing, informal or insulting tone?					
		2	If a human-like entity (including avatar(s)) is used, is it usage warranted (as opposed to technological curiosity) ?					

Table 3. Reliability criteria for user/system interfaces

	Criteria		Questions	Yes	No: Accept	No: Improve	No: Reject	Comments
3.1	Error prevention	1	Does the interface screen user inputs to prevent errors?					
		2	Can the interface filter the outputs to intercept unacceptable (and possibly dangerous) ones?					
3.2	Error tolerance	1	In case of user error, does the interface allow return to the previous state without side effects?					
3.3	Caution	1	Does the interface require confirmation of users for any irreversible action?					
		2	Does the interface support "undo" operation at any desirable level?					
3.4	Predictability	1	Does the interface do what its users would expect it to do?					
3.5	Access reliability	1	Does the interface allow control of access to the system?					
		2	Is the interface capable of monitoring access to the system and report it (off-line, on-line)?					

Table 4. Evolvability criteria for user/system interfaces

	Criteria		Questions	Yes	No: Accept	No: Improve	No: Reject	Comments
4.1	Adaptability	1	Can the interface provide information needed by different categories of users such as experts, transfer users, occasional users and novices? (e.g., are there shortcuts for expert users?)					
4.2	Customizability	1	Does the interface support preferences?					
		2	Is it possible to change the natural language that is used in the interface?					
4.3	Learning ability	1	Can the interface remember the usage and habits of users?					
4.4	Maintainability	1	Can one easily maintain the interface?					
4.5	Portability	1	Can one use the same interface on different platforms?					

ICS/ISTAR BALANCE OF INVESTMENT METHODS STUDY

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1. INTRODUCTION

1.1 The Centre for Defence Analysis (CDA) within DERA are currently developing a top-down approach to Balance of Investment (BoI) in ICS (Information and Communication Systems) and ISTAR (Intelligence Surveillance Target Acquisition and Reconnaissance) systems. The method aims to assess the benefits of investment in battlefield ICS and ISTAR capabilities and to meet the need for investment in ICS systems to be evaluated alongside weapon systems using the same high level measures of effectiveness. The method also provides insight into the nature and levels of ICS and ISTAR capabilities needed to support planned future concepts of operation.

1.2 An approach has been developed which is based around the use of constructive simulation models of theatre level warfare. An important part of the method involves identifying the key information flows which would occur during a campaign.

1.3 The method enables:

(a) identification of the ICS and ISTAR capabilities needed to support planned future concepts of operations;

(b) comparison of these with existing and planned procurement;

(c) identification of excesses or shortfalls;

(d) and measurement of the effect of any shortfalls on the conduct and outcome of an operation.

1.4 In addition, to contribute fully to the balance of investment debate, the methodology should ideally be able to assess the balance of investment across the full spectrum of land, air and maritime warfare, including joint and combined operations, from a tactical to strategic level.

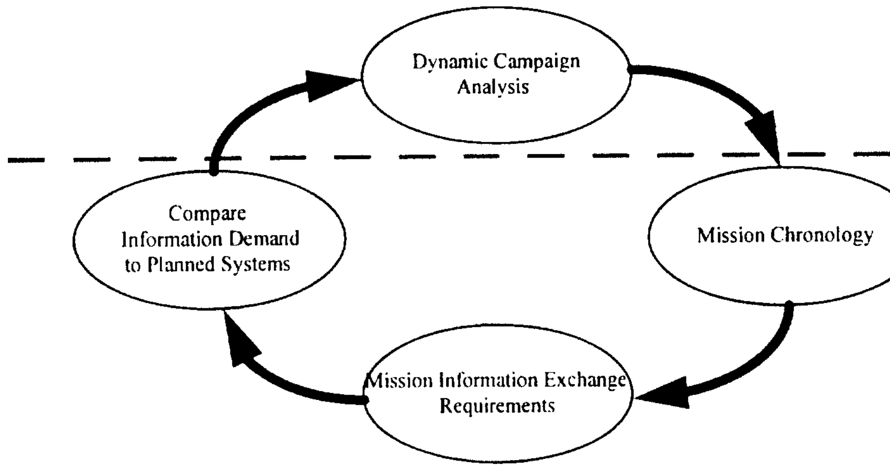
2. THE TOP DOWN METHODOLOGY

2.1 The methodology is a top down approach that starts by considering the campaign. Mission based campaign level combat simulation models are used widely in CDA to address issues such as the effectiveness of weapons, platforms and ISTAR systems. The novel aspect of this methodology is the creation of a direct link between the combat missions within such dynamic campaigns and the information flows which underpin them. This linkage allows a top-level assessment to be made of the ICS and ISTAR capabilities needed to support specific concepts of operations, including first-order approximations of the communication capacity demands imposed by ICS systems.

2.2 A schematic of the generic methodology is provided in Figure 1. It has two primary components: an ability to assess the capacity demands arising from the use of ICS systems within

a campaign; and an ability to assess the impact of different levels of investment in ICS and ISTAR systems.

Assess impact of ICS and ISTAR



ICS capacity analysis

Figure 1: The generic method

2.3 The premise of the method is that the output of any campaign analysis can be broken into a time-ordered set of combat missions and that the information demands underpinning the conduct and success of each of those missions can be captured and quantified in some way. The identified demands are mapped against planned system capabilities allowing identification of when and where potential excesses or shortfalls might occur. The possible impacts of these differences are then investigated by revisiting the campaign analysis and modifying the affected missions, e.g. by delaying the time at which specific missions could occur, or by reducing the availability of ISTAR system information. A rerun of the campaign quantifies the effect in terms of the impact on the overall campaign measures of effectiveness.

3. LAND/AIR DOMAIN

3.1 Due to the availability of tools, initially the method has focused on war fighting operations in the land/air domain. The dynamic campaign analysis used is the CDA theatre-level land/air model CLARION. A key feature of CLARION for application in this method is that it is a mission based command and control led model. It allows representation of different concepts of operation in various scenarios and simulates the effectiveness of platforms, weapons and ISTAR sensors. It also includes a simple representation of Command, Control, Communications and Intelligence (C3I) which allows the effect of capability gaps and the impact of potential degradation to be quantified.

3.2 CLARION does not model communication architectures. Calculation of whether a modelled concept of operations is compatible with planned ICS and ISTAR systems must therefore be carried out by post-processing using mission-related Information Exchange Requirements (IERs) templates. The templates are the baseline set of data which describe the information flows underlying a specific combat mission type. The main advantage of the method is that the data and assumptions used in the mission IER templates are clear and structured. This allows the data to be easily varied in order to investigate new technologies and concepts of operations. The

mission templates are independent of scenario, system and technology to allow the method to be used on any scenario and consider several different information and ISTAR systems.

3.3 The land/air methodology incorporates 5 specific land/air mission types, plus tactical background IERs and strategic IERs. The tactical background IERs incorporate the flow of information occurring in the background of the campaign at divisional command level and below such as logistics reports. The Strategic IERs covers aspects relevant to the campaign at MOD HQ level to the component commander level, for example, policy directives being sent from the Ministry of Defence to in-theatre commanders. The strategic elements, by definition, will incorporate issues across all three services.

3.4 The templates are shown in Figure 2 below:

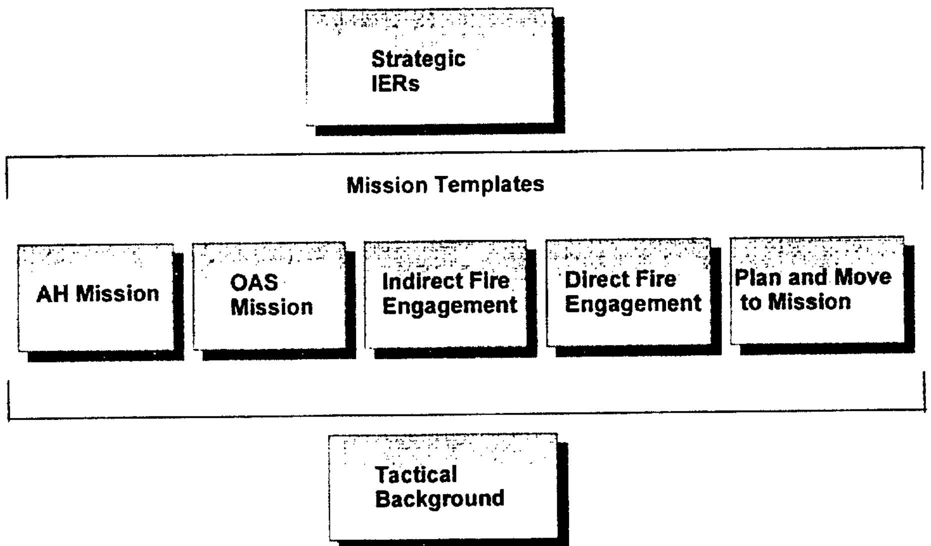


Figure 2: Land/Air missions

3.5 The specific mission types were selected based on the missions within CLARION.

4. INFORMATION EXCHANGE REQUIREMENT CAPTURE

4.1 Within the study an IER is defined as a flow of information between a specified source and destination. The IER can be defined by a number of characteristics which fully describe the information flow. The IER expresses the user requirement to exchange information and is independent of the supporting ICS/ISTAR configuration and technology.

4.2 The following process was implemented to gather the IER data fo~ ~ach mission template shown in figure 2 above:

(a) The development of a task analysis for each mission type to describe the activities conducted within the mission. (See paragraph 4.3)

(b) Drawing on other studies, databases, sources and military judgement, to identify IERs and map them on to each task within the task analysis to form the IER templates.

(c) A review of the templates by relevant external organisations to ensure the data captured is a reasonable representation of likely activity.

Task Analysis

4.3 In order to identify the IERs for each mission and to produce a consistent basis from which to analyse IERs from other databases and sources, it was necessary to examine each of the selected missions in depth. A task analysis was performed on each mission where the objective was to break down the mission type into the component tasks required to achieve the mission. Figure 3 is a simple example of a breakdown of an attack helicopter mission. Each level of the structure provides more detail on the task above. The breakdown should continue until it is possible to identify the information requirements to achieve each particular sub task.

Mission Breakdown

- 1 AH mission
    - 1.1. Requested Support
        - 1.1.1 Request to Division
        - 1.1.2 Request to Sqn
    - 1.2 Plan mission
        - 1.2.1 Analysis
        - 1.2.2 Route
    - 1.3 Execute mission
    - 1.4 Post execution

Figure 3: AH Task analysis

4.4 Each task within the breakdown has a task identification number which provides a clear link between the tasks within the mission and the resulting flow of information in the IER templates.

Information Exchange Requirement Templates

4.5 The IER mission templates have been constructed, where possible, from existing IER databases and sources. Several sources of IERs were identified for each mission and CDA military judgement was used to attribute them to the tasks in the task analysis. CDA military judgement was used to generate data when it was not available from any existing source.

4.6 For each individual IER, the characteristics captured are as follows:

(a) **Task ID**. This identification number links the individual IER to a particular task in the relevant task analysis. This link is extremely important for data audit purposes and transparency of the IER templates.

(b) **Source**. The entity initiating the information flow.

(c) **Destination**. The entity or entities receiving the information flow. This column could include more than one entity.

(d) **Distribution**. This category shows the number of destinations that the information is sent to.

(e) **Information Type**. The information type of the IER is a high level description of the content of the message being sent. An example would be a warning order or intelligence report.

(f) **Priority**. Each IER has a priority in terms of Very High, High, Medium, Low or Very Low.

(g) **Media Types**. Whether the IER is data, fax, video, voice, graphics or imagery.

(h) **Start Time**. This characteristic allows the IERs to be placed in sequence. The start time is measured in hours and minutes relative to the start of the mission.

(i) **Size**. The size of the IER is measured in minutes, characters, graphics or number of pages of a particular paper size.

(j) **Frequency**. The frequency of the IER represents how often the IER is repeated within the mission or campaign.

5 COMET POST-PROCESSOR

5.1 The IER templates form a baseline set of data for use in any study. Application of the templates in a study is achieved through the use of a post-processor, COMET, which captures the specific assumptions to be used regarding information systems and bearers. COMET has been developed to examine how the demand for information varies over the duration of a campaign and explore how the demand can be managed. COMET imports the missions which occurred in the campaign under review and based on the mission IER templates generates a full list of all the IERs throughout the campaign. Each IER is assigned to a particular information system based on the information type (i.e. warning order, logistic report) of the flow and the medium type (i.e. data, voice etc.) and mapped to the appropriate bearer system based on the source and recipient of the information flow. Each IER has a data rate, which is based on the medium type and bearer system, from which the peak and mean loading requirement on the information and bearer systems to be calculated. The loadings are produced over the whole duration of the campaign. Figure 4 shows a schematic of the COMET database, where each IER is mapped to a particular information and bearer system. Figure 5 shows an example of the type of output gained from COMET.

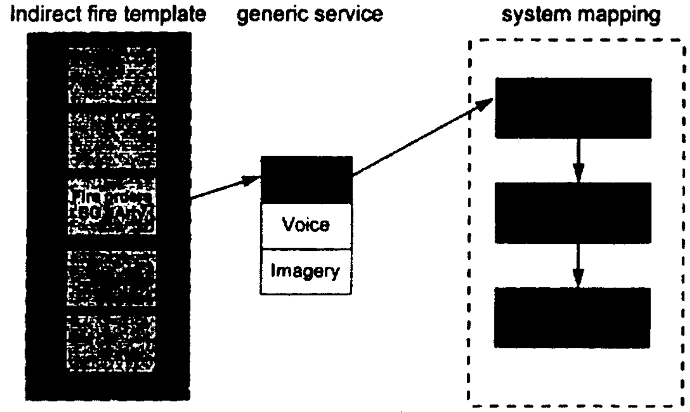


Figure 4: Schematic of COMET post-processor

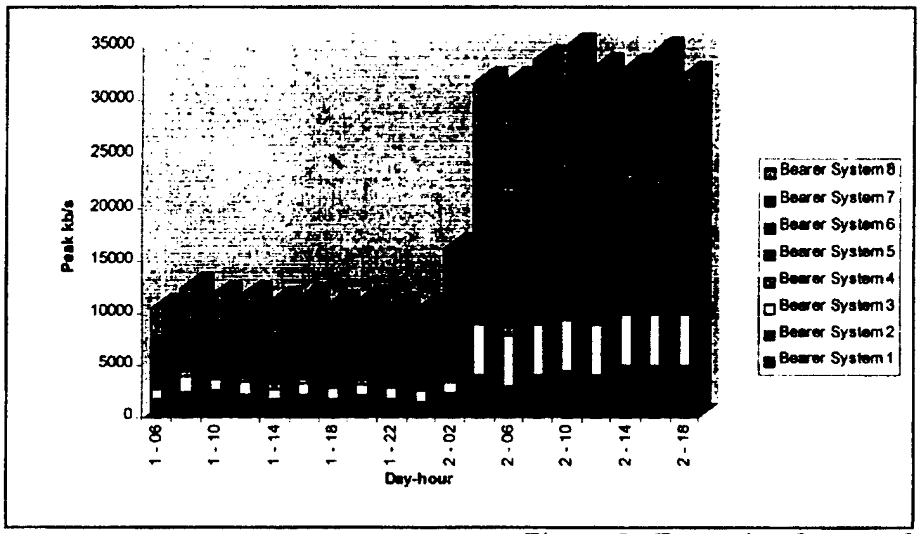


Figure 5: Example of output from COMET

5.2 Once COMET has calculated the mean and peak loading on each bearer system and information system this can then be compared to actual performance figures. Based on this information and lower level communication modelling, delays can be fed back into the dynamic campaign model in order to show the effect on the campaign outcome. The effect is therefore measured in terms of high level measures of effectiveness such as casualties incurred in achieving the campaign objective.

6. FUTURE WORK

6.1 Work to date has focused on the land/air domain using the CDA model CLARION. Equivalent models for maritime, air and Operations Other Than War are currently under development to enable the method to analyse the information demands across joint and combined operations.

7 CONCLUSIONS

7.1 It is considered feasible to use the above approach to examine many of the issues surrounding balance of investment in ICS and ISTAR, across the spectrum of land, air and maritime warfare including joint and combined operations. The method provides insight into the nature and levels of ICS and ISTAR capabilities needed to support planned future concepts of

operation, comparison of these with existing and planned procurement, assessment of the impact of ICS on high level measures of effectiveness, and analysis into a variety of issues such as concurrency, interoperability, capacity demand, manoeuvrability and connectivity. As in all high level analysis, the level of success in application of the method will ultimately be subject to the limitations and availability of lower level data.

8. GLOSSARY

AH	Attack Helicopter
Arty	Artillery
BG	Battle group
BOI	Balance of Investment
C3I	Command, Control, Communications and Intelligence
CDA	Centre for Defence Analysis
COMET	Communications Evaluation Tool
CLARION	Combined Land Air Representation of Integrated Operations
DERA	Defence Evaluation Research Agency
ICS	Information Communications Systems
IER	Information Exchange Requirement
ISTAR	Intelligence Surveillance Target Acquisition Reconnaissance
MOD	Ministry of Defence
OAS	Offensive Air Support

Digitization and the Analysis Process, Lessons Learned from the Assessment of the U.S. Army's Task Force XXI

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"The Information Age is upon us. The view of the future we see emerging envisions a new battlefield: one where we gather, process, and use information differently than ever before. This information will then empower us as we field and fight the most lethal land force in the world." (TF XXI Final Report, Executive Summary)

General William Hartzog, U.S. Army Training and Doctrine Command Commander

INTRODUCTION

In March 1997, the U.S. Army executed one of the most complex experiments in the history of land warfare. Utilizing thousands of pieces of advanced equipment and nearly ten thousand soldiers, evaluators, civilian employees, and contractors, the U.S. Army glimpsed the potential garnered from information age technologies. The experiment was conducted in the vastness of the National Training Center (NTC), Fort Irwin, California, on Army installations such as Fort Hood, Texas, and in analytical agencies such as the U.S. Army's Training and Doctrine Command (TRADOC) Analysis Center (TRAC), White Sands Missile Range (WSMR), New Mexico.

This paper develops the process, models, and lessons learned from the support of the Task Force XXI (TF XXI) Advanced Warfighting Experiment (AWE). First, the TF XXI AWE process is examined with a review of terms, the hypothesis definition process, AWE objectives, information systems, key participants, and experiment initiatives. Next the reader is given an overview of the assessment process that followed the Model-Experiment-Model (MEM) methodology. The MEM discussion details how to replicate field exercises with increased fidelity, limitations, models used, MOEs/MOPs, and "digitizing" the scenarios. Finally, detailed analysis, with models such as Janus and the Combined Arms and Support Task Force Evaluation Model (CASTFOREM), is conducted with results. The paper is concluded by a review of lessons learned and how these lessons will benefit military decision making.

The TF XXI AWE was one of a series of AWEs whose end state is the building of a digitized division and corps. Lessons from each AWE have been transferred to follow-on AWEs as leaders and soldiers learned how to use information age technologies. (TF XXI Experiment Concept, p. 1-1)

The TF XXI AWE consisted of live and constructive simulations starting in March 1996 and extending through August 1997. The TF XXI AWE focused on building the digitized Brigade Combat Team (BCT). The BCT was organized as one mechanized infantry task force, one armored task force, one light infantry battalion, an aviation task force, and brigade support elements. (TF XXI Experiment Concept, p. 1-1)

The live simulation centered upon training events that were conducted by the 4th Infantry Division (Mechanized) (4ID), Fort Hood, Texas and 1-5th Infantry (Light), Fort Lewis, Washington. These exercises built from the soldier to brigade operations. The primary goals were to collect data and assess what value is gained by information age technologies, organizational changes, and new equipment initiatives. (TF XXI Experiment Concept, p. 1-1)

The constructive simulation grew from the training exercises following the MEM methodology. Starting at the system level, each modeling effort evolved from the lessons learned from the previous. The modelers developed increasingly more complex tactical situations as the effort grew from the platoon, to company, onto the task force and brigade. In other words, each successive modeling effort used data and lessons from previous tests to calibrate their models. (TF XXI Experiment Concept, p. 1-1)

Multiple decision support products were produced by the TF XXI AWE process. These products were used by senior U.S. Army decision makers in critical budget decisions and in defining the future direction for the 21st century Army. Some of the products were: Appliqué/Tactical Internet Milestone I/II decisions, digitized brigade observations for use in the Division XXI redesign, insights on TF XXI and Joint Venture issues, and refined tactics, techniques, and procedures (TTPs) for digitized brigade operations. (TF XXI Experiment Concept, p. 1-1)

In support of this process, TRAC's purpose was to assess the value gained by Digitization of the Battlefield (DOTBF). DOTBF is the most important challenge that the U.S. Army will address in this decade and required progressive modeling and simulation. DOTBF is defined as: the application of technologies to acquire, exchange, and employ timely information throughout the battlespace, tailored to the needs of each commander, shooter, and supporter.

DOTBF is at the heart of C3I. For example, how does the 21st century commander exercise authority and control over assigned forces in the accomplishment of the mission? What arrangements of personnel, equipment, communications, facilities, and procedures are employed by that commander in planning, directing, and controlling forces and operations? The use of information age technology, in particular digitization, is the U.S. Army's chosen path for answering the C3I challenges of the next century. National decision makers must determine how do assess digitization and other information age concepts? TRAC was one of the organizations chosen to answer these questions.

In consonance with the Symposium's theme, the TF XXI assessment demonstrates the latest research results in the U.S. Army's process of conducting systematic and disciplined evaluations of C3I systems. Also, this paper presents some of the current best practices of military operations analysis and methodologies relating to defense planning and decision making.

COMMON TERMINOLOGY

Reaching an understanding on common terms is at times difficult. For this paper, the concepts of modeling and simulation are defined from sources such as the U.S. Army Model and Simulation Master Plan and DoD 5000.61. These terms are presented to inform this Symposium's diverse audience of the terms used by the U.S. during the TF XXI AWE process.

Battle Command: The process of assimilating thousands of bits of information and using the data to visualize the battlefield, assess the situation, and direct military action required to achieve victory.

Constructive: Aggregated software representation of units, their behavior, associated outcomes, and support operations using rules, data, and procedures designed to depict an actual or real world situation. (U.S. Army Model and Simulation Master Plan)

Linked Modeling and Simulation: Outputs of one model or simulation that serves as inputs to another model or simulation. (Simulation Support Plan)

Live: Representation of military operations using live forces and simulated weapons effects and/or instrumented systems interacting on training, test, and exercise ranges which simulate experiences of actual operational concepts. (Army Model and Simulation Master Plan)

Model: A physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process. (DoD 5000.61)

Simulation: A method for implementing a model over time. Also, a technique for testing, analysis, or training in which real-world systems are used, or where real-world and conceptual systems are reproduced by a model. (DoD 5000.61)

Situational Awareness: The ability to maintain a constant, clear mental "picture" of the tactical situation. This picture includes an understanding of terrain and the relationship between friendly and enemy forces.

Validation: The process of determining the extent to which modeling and simulation is an accurate representation of the real world with the perspective of the intended use. (Army Regulation 5-11)

Verification: The process of determining that a modeling and simulation implementation accurately represent the developer's conceptual description and specifications. Verification evaluates the extent to which the modeling and simulation has been developed using sound and established software engineering techniques. (Army Regulation 5-11)

Virtual: Representation (synthetic) of a warfighting environment patterned after the simulated organization, operations, and equipment of actual military units. (Army Model and Simulation Master Plan)

Models and simulation are critical components of the decision making process. Why the Army selected this approach was influenced by several goals. These goals were to reduce risk, time, and resources required in the acquisition process. Additional goals included improved quality, usefulness, dependability, and supportability of evolving military systems. Furthermore, the Army sought further refinement of the requirements, design, testing, production, and fielding issues. (Simulation Support Plan Guidelines, May 1997, p. 2)

HYPOTHESIS DEFINITION PROCESS

The TF XXI AWE process focused on one central hypothesis. This central hypothesis was: *If information age battle command capabilities and connectivity exist across all battlefield operating system functions, then increases in lethality, survivability, and tempo will be achieved.*

Analysis was conducted and two further hypotheses were developed that answered specific points of the TF XXI hypothesis. These two hypotheses were called the NTC Hypothesis and the Modeling Hypothesis.

The NTC Hypothesis was: *Introducing prototype technologies and organizational structures in heavy and light forces should provide, evidence for* ***potential*** *improvements*

in force capabilities and more refined requirements for Force XXI. The key component in the NTC Hypothesis was the identification of potential.

The Modeling Hypothesis was: *If the observed potential were exploited, then an increase in survivability, lethality, and/or tempo would occur.*

The use of simulations to answer the Modeling Hypothesis was the key to the MEM approach. The March 1997 NTC rotation was a single event, in other words, a sample size of one. Modeling and simulations were used to expand this sample size too many. This expansion of sample size allowed the ability to examine potential and answer questions from senior Army leadership such as what changes were found in combat effectiveness, survivability, lethality, and tempo.

AWE OBJECTIVES

The TF XXI AWE was guided by five objectives. These objectives coupled with the Hypotheses provided a framework for the analytical process. The AWE objectives were:

- Does digitization have an impact on the control of forces?
- Does the new Combat Service Support (CSS) structures contribute to force effectiveness?
- Do new weapons/technologies contribute to force effectiveness?
- Are changes required in command and control (C2), organization, and processes?
- Do new tactics, techniques, and procedures (TTPs) have an impact on force effectiveness?

PARTICIPANTS

To complete such a complex experiment required the coordinated participation of several diverse organizations. Each organization was responsible for a critical portion of the experiment. Described below are the missions of selected TF XXI players. This list is not comprehensive. Many other organizations had important roles that impacted the assessment process.

- TRAC-WSMR: Answer the AWE hypothesis and Joint Ventures using **constructive modeling**. Answer training related issues.
- OEC (Operational Evaluation Command): Answer the AWE hypothesis and Joint Venture issues using **live experiment testing**.
- TEXCOM (Test and Evaluation Command): Collect data from the TF XXI experiment. Provide the data to TRAC-WSMR and OEC for their analysis.
- TRAC-LEE (Fort Lee, Virginia): Answer Combat Service Support initiatives.

- LIWA (Land Information Warfare Activity): Conduct a vulnerabilities assessment of digitization.

- ARI (Army Research Institute): Conduct a human dimensional impact assessment.

INFORMATION SYSTEMS

Battlefield digitization is the primary focus of the technological advances examined during the TF XXI AWE. Digitization supports the concept that information is power. In other words, a key factor in modern warfare is the ability to collect, process, disseminate, and use information about the enemy while denying him similar information about friendly forces. The brigade's ability to transmit, receive, and display digital data is fundamental to winning the information war.

The computer based system, Appliqué, in support of the Force XXI Battle Command Brigade and Below (FBCB2) was installed on weapon and C2 platforms within the brigade. Appliqué is the central focus of the TF XXI AWE's effort to digitize the battlefield. Appliqué is an integrated set of software, hardware, and supporting systems. Appliqué supports the lower echelon units with near real-time situational awareness. Appliqué seeks to share a common picture of the brigade environment. This shared picture is given by graphical displays showing friendly units, enemy locations, and appropriate graphical control measures. Appliqué provides C2 connectivity required by soldiers, weapons, and C2 platforms at the forward edge of the battle area. (TF XXI Experiment Concept, p. 1-3 and p. 4-1)

Many other information systems, besides Appliqué, were examined during the TF XXI AWE process. A sample of these systems or architectures, that were in the experiment, are discussed in subsequent paragraphs.

The Army Battle Command System (ABCS) is an umbrella architecture that has evolved to incorporate the Army's C2 systems from strategic to tactical. ABCS's objective is the integration of real-time situational information into the force-level database with near real-time access. ABCS is evolving with various subsystems at differing levels of integration. (Army Magazine, October 1996, pp. 264-265)

The Army Tactical Command and Control System (ATCCS) is the Army's comprehensive approach to automating and improving its tactical C2 systems. ATCCS has five subsystems: the maneuver control system (MCS) for monitoring troop movements and battlefield conditions; the forward area air defense command and control (FAADC2) supports short-range air defense weapons; the all-source analysis system (ASAS) facilitates the reception, analysis, and dissemination of intelligence and electronic warfare information; the advanced field artillery tactical data system (AFATDS) assists in controlling indirect fires; and the combined service support control system (CSSCS) monitors supply, maintenance, transportation, medical, personnel, and logistical activities. These systems are linked by three communication systems: the Army data distribution system, the mobile subscriber equipment (MSE) system, and the single-channel ground and airborne radio system (SINCGARS). (Army Magazine, October 1996, pp. 265-267)

FBCB2 is best described as both a system and a concept that crosses all battlefield operating systems (BOS). FBCB2 seeks to support battle command functions by providing horizontal and vertical integration of data and information that should provide one homogenous battle command architecture. (Army Magazine, October 1996, p. 269)

TF XXI AWE INTIATIVES AND ISSUES

TRAC's major focus was the assessment of digitization, however, the TF XXI AWE process contained 72 initiatives that covered the breadth of equipment, organizational changes, new doctrine, digitized tactics, and processes. As stated in the TF XXI Experiment Concept, "The Army does not fight with one system at a time, but as a combined arms team synchronizing all assets and their capabilities on the battlefield. The TF XXI AWE will provide the same free flow (of) operations and decisions that would be expected on the battlefield." (TF XXI Experiment Concept, p. 1-4)

MODEL-EXPERIMENT-MODEL METHODOLOGY

The Model-Experiment-Model (MEM) methodology was the foundation for the TF XXI AWE assessment. The initial Modeling phase's objective (pre-experiment) was to replicate selected scenarios (unit exercises prior to the March 1997, AWE NTC rotation). TRAC-WSMR used data collected during Fort Hood training, and other events, to develop and calibrate models such as CASTFOREM and Janus. The products from the first modeling effort included a comparison of base and digitized cases. The second phase, the Experiment (exercise) provided the opportunity for data collection, insights, and experience that became the basis for the evaluation of TF XXI issues and initiatives. The second Modeling phase (post-experiment) evolved from the live event. Also, in the second Modeling phase, models were used to create the unique extension of exploring digital opportunities. In this phase, analysis was conducted on the differing courses of action provided by digitization. A validation effort (model calibration/performance baseline) was used, in every phase, with a comparison of live force effectiveness to modeled force effectiveness. This validation concept allowed TRAC-WSMR to calibrate the models and to establish revised baselines. (Appendix B: TF XXI Live Simulation Assessment Plan to Annex C, TF XXI Analysis Plan, pp. C-b-6 to C-b-7)

MEM AND EXPERIMENT LIMITATIONS

Limitations exist in each type of experiment and the TF XXI AWE process was no exception. For example, along with the experiment the brigade was concurrently conducting "training" that could be counter-productive to experimental purity. Limits exist in the control of variables that are required to support analysis. In other words, an analyst can not order a unit to conduct 30 trials of an event to obtain a larger sample size.

Other limitations included software and system maturity that evolved on a continuous basis, introducing analytical problems. Coupled with equipment evolution was the continuos development of how to use that equipment and the development of TTPs and doctrine.

Statistical experimental significance was another challenge. The introduction of multiple systems, that are under evaluation, makes it difficult to isolate the impact of one single system. (Appendix B: TF XXI Live Simulation Assessment Plan to Annex C, TF XXI Analysis Plan, pp. C-b-6 to C-b-8)

As mentioned earlier, the TF XXI AWE (NTC rotation) was a single, non-repeatable event, that by itself, makes it difficult for comparison to a baseline or to alternative force designs. This problem was mitigated by the final modeling phase of the MEM methodology.

MODELS USED

The Combined Arms and Support Task Force Evaluation Model (CASTFOREM) and Janus were the two models used to support constructive simulation.

CASTFOREM is a high-resolution, two-sided, force-on-force, stochastic, event-sequenced, systemic simulation model of a combined arms operation. CASTFOREM portrays individual combat systems and a robust decision-making process. CASTFOREM was developed at TRAC-WSMR. CASTFOREM is the highest resolution, lowest hierarchical model in the Army's Model Improvement Program. CASTFOREM uses Mobility, Firepower, and Mobility/Firepower Loss-of-Function values, personnel loss, and K-kill to calculate "kills." The probability of hitting the target is calculated first. This probability is a function of weapon, target, exposure, movement conditions, and range. Overall kill probabilities are obtained by multiplying the probability of hitting the target with the probability of kill given a hit.

CASTFOREM features a decision table methodology that forms the basis of its flexibility. The battle is orchestrated through the use of decision tables that are event activated. Decision tables are used to control unit responses to battlefield conditions. For example, if Appliqué provides information about an event, a decision table is referenced to determine the unit's course of action.

Janus is an interactive, event sequenced, closed, stochastic, ground combat simulation featuring high resolution and precise color graphics. Janus has matured at TRAC-WSMR and requires interaction between opposing sides. This unique process replicates dynamic human decision-making with each player directing Janus during the combat simulation.

MEASURES OF EFFECTIVENESS AND PERFORMANCE (ASSESSMENT)

How do analysts assess a process that contains 72 initiatives that exist across the entire spectrum of BOS functions (C2, Intelligence/Electronic Warfare, Maneuver, Fire Support, Air Defense Artillery, Mobility/Survivability, CSS)? No single assessment measure exists that answers all the questions asked by Army decision makers. The best solution is to develop a "set" of measures that cover the entire range of issues. All of these measures will not be developed in this paper however, several examples are given. For example, representative measures from the categories of lethality, survivability, tempo, battle command (Appliqué), battle command (communications), and supportability are presented.

Lethality is one critical measure of force effectiveness. In comparison with the baseline force, what is the ability of the TF XXI brigade to destroy an opposing force? To answer this question, measures that address lethality, engagement ranges, and engagement outcomes were examined. One measure was the Loss Exchange Ratio (LER). LER analysis was used to determine enhancements to force lethality that might be attributed to digitization. (Appendix B: TF XXI Live Simulation Assessment Plan to Annex C, TF XXI Analysis Plan, p. C-b-10, p. C-b-12)

Survivability of a force is another key parameter. In comparison with the baseline force, what is the ability of the TF XXI brigade to survive an opposing force? The tactical situation is examined to determine contributing factors to blue survival. These factors may include killing system ranges, weather, terrain usage, visibility, communications effectiveness, and red weapon effectiveness. The number of occurrences and causes of fratricide is one measure of survivability. If digitization provides the unit with more effective control of sub-unit locations, there should be a corresponding reduction in the

engagement of other friendly forces. (Appendix B: TF XXI Live Simulation Assessment Plan to Annex C, TF XXI Analysis Plan, pp. C-b-15 to C-b-16)

Tempo is another area of analysis. In comparison with the baseline force, does the digital force show an improvement in the ability to control their forces using concepts such as timing, maneuver, synchronization, and C2? One example of tempo is the timeliness of reporting. If digitized forces can disseminate orders and messages faster and more accurately, then there should be an increase in battlefield tempo and improved situational awareness. Key message types that were monitored included time differences in the dissemination of fragmentary orders, spot reports, situation reports, calls for fire, obstacle reports, NBC messages, and warning orders. (Appendix B: TF XXI Live Simulation Assessment Plan to Annex C, TF XXI Analysis Plan, pp. C-b-19 to C-b-20)

Battle Command (Appliqué) is the measure of how does digitization improve the ability of the commander to control his forces. The analyst seeks to determine the power of digitization to control blue forces and defeat the enemy. One component is the "awareness" of the friendly situation. Quantitatively, what is difference between friendly unit locations and actual ground truth. (Appendix B: TF XXI Live Simulation Assessment Plan to Annex C, TF XXI Analysis Plan, pp. C-b-22 to C-b-23)

Battle Command (communications) addresses the ability of units equipped with modern communications systems to efficiently and accurately transmit command information. Timeliness and system effectiveness are used to define this issue. For example, the measure of message completion rates is examined. If the digitized unit is able to successfully transmit a higher number of messages between units, in a timely manner, then effectiveness should be enhanced. (Appendix B: TF XXI Live Simulation Assessment Plan to Annex C, TF XXI Analysis Plan, p. C-b-24)

Supportability is used to assess the ability of the TF XXI brigade to sustain itself. Logistical operations are critical in maintaining combat operations. One measure of supportability is the unit's ability to conduct follow-on missions shown by its equipment readiness rate.

Blind adherence to measures such as LERs will not answer all the questions asked by decision makers. One example from the AWE was when the blue force was fixed in position by red and blue inaction. This fixed blue force was then penetrated in another sector with red pushing deep into blue's rear area, achieving victory. The blue LER was "acceptable" however, the reality is that red achieved success.

INITIAL MODELING PHASE (PRE-EXPERIMENT)

This section develops the initial modeling phase by explaining the training, preparation, and analytical efforts prior to the March 1997, AWE. The goal of this phase was to quantify the potential contribution of digitization to brigade force effectiveness. This effort focused on building Fort Hood/Task Force scenarios and a brigade movement to contact (MTC). The Fort Hood experience has been discussed in papers by TRAC-WSMR analyst, Mr. Kevin Young. See his work for a more detailed explanation.

The Fort Hood/Task Force scenarios replicated actual Fort Hood field exercises that used non-digitized and digitized forces. The Fort Hood scenarios provided an analytical foundation for the MEM methodology. These critical first steps refined how field data is incorporated into constructive modeling, how to verify the replicated scenarios, and the evolution of measures of effectiveness. This Fort Hood work was the foundation of the

AWE modeling effort with techniques and methodologies being applied in subsequent phases.

Movement to Contact (MTC) Predictive Scenario

The MTC scenario was developed from observations of Fort Hood exercises and lessons learned from initial modeling efforts. The brigade conducted a movement to contact against an aggressive NTC Opposing Force (OPFOR). The MTC scenario explored the impact that digitization would have on combat effectiveness. Also, the scenario provided a performance estimate for the AWE's movement to contact mission.

The blue "digitized" brigade was composed of two task forces: Task Force 1-22 Infantry and Task Force 3-66 Armor. The blue force is opposed by a motorized rifle regiment. The brigade's light infantry battalion (1-5 Infantry) was defending a division asset and was not simulated.

The scenario portrayed a realistic NTC situation that isolated the effects of Appliqué, brigade scouts, and related technologies. The scenario stressed the brigade with an aggressive, well-trained OPFOR. Furthermore, the blue commander was not allowed full use of artillery smart munitions and aviation platforms. For example, AH-64s were not modeled, to avoid the possibility of blue success being based upon one weapon system and not the impact of information technologies.

A three step process was used to model the MTC. While the "live" AWE MTC reflected a digitized Blue force, the first step was to model the MTC mission in CASTFOREM without digitization. This step established a base case. Step two compared combat effectiveness of this predictive non-digitized MTC with a previous NTC "standard" rotations. Step two verified that the preliminary CASTFOREM results were reasonable. Step three was the development of a digitized MTC scenario. The results from the non-digitized and digitized versions were then compared to determine the impact of digitization on combat. This multi-step process produced an estimate of potential increases in lethality, survivability, and battle tempo prior to the AWE.

Movement to Contact - Planning

The enemy situation is normally vague or unknown when a unit is given a movement to contact mission. Blue must carefully analyze the terrain and plan for the worst threat case, as the commander would not want to underestimate the enemy. Potential threat locations, observation posts, engagement areas, courses of action, and obstacles are among the factors that must be identified early and incorporated into the blue plan.

The primary consideration in planning a movement to contact is the determination of action for maneuver and fire support when contact is made. The brigade commander must ensure that subordinate commanders understand their missions within the context of his intent. Also, brigade units must follow reporting procedures. As the enemy situation develops, the timely flow of information from units such as the brigade scouts is important.

The OPFOR is well trained and prepared for the collision of two forces (a meeting battle). The red regiment will make contact with a rapid tempo, gain the initiative, and force the blue commander to react to the red plan.

When enemy contact is established the brigade usually conducts a hasty attack or hasty defense. The principle of the hasty attack is to seize the initiative. Before mounting a hasty attack, the commander develops the situation, determines enemy strength, and rapidly

masses firepower from the resources available. By retaining or regaining the initiative, the brigade commander can follow the course of action that improves his chances for mission success.

The hasty defense is usually employed to shape the battlefield. The selection of a hasty battle position represents the culmination of the brigade's intelligence preparation of the battlefield and estimate process. The brigade S-2 has identified threat avenues of approach and the key terrain dominating those approaches. The blue commander places forces to exploit the intelligence picture.

The hasty defense mission is assigned to tactical units that can best defeat the red force. Four factors are considered when forming a hasty defense. These factors are: the reduced Pk at extended ranges, the likelihood of a dirty battlefield (to include obscurants), the number of threat systems, and the attacker's speed.

The blue commander must shape the situation such that decisive engagement is achieved on as favorable terms as possible. The blue commander must control the number of threat vehicles confronted at one time. Selecting restrictive terrain (e.g., choke points) helps to regulate the movement of the attacker into the designated engagement area.

These planning factors are influenced by information technologies. How technologies are used to win the fight is the commander's challenge.

Movement to Contact - Execution

The brigade's plan was for TF 1-22 to lead the brigade to the objective. On order, TF 3-66 would follow and bypass TF 1-22 to either the north or south and continue advancing towards follow-on objectives. Movement is along one of three axes. Axis selection is dependent upon the threat and evolving situation.

In the digitized MTC, the brigade commander receives intelligence about threat locations (e.g., from the brigade scouts) by digital C2 messages. As TF 1-22 approaches a critical decision point, the brigade commander observes that the OPFOR will reach his objective (which is key terrain) prior to TF 1-22. The brigade commander issues a fragmentary order for TF 1-22 to assume a hasty defensive position and defeat the forward security element (FSE) and fix the advance guard main body (AGMB). Because of timely digital information, the brigade commander commits his reserve (one Armor company) to support the TF 1-22 defense. With the massing of Blue forces, the FSE and AGMB are defeated. The regiment's main body is separated by time and distance. TF 1-22 (-) reorients to face the main body while TF 3-66 maneuvers against the main body's flank. Digital information provided the commander with situational awareness of blue and red forces. This information allowed the brigade to achieve decisive, local superiority. Coupled with rapid maneuver, the brigade caused the piecemeal destruction of red.

The movement to contact modeling established bounds or expectations on the upcoming live experiment. The initial modeling phase provided Army leadership with a glimpse into the potential of information technologies.

EXPERIMENT (EXCERCISE)

The experiment (exercise) phase of the MEM methodology involved evaluation of the March 1997 AWE NTC rotation. During the first half of the NTC rotation, the brigade conducted "traditional" missions: movement to contact, defense in sector, and deliberate attack. The second half was a series of exercises called "TRADOC 525-5" missions. These

525-5 missions were different from the "traditional" because the brigade was assigned a larger battle space, a short planning time was allowed, and continuous operations without "preparation" days were given. Some purposes of the 525-5 missions were to explore the outer bounds of digitization, to stress the unit, and to measure what a digitized unit can accomplish under increased demands.

The AWE provided substantial data that required analysis. The Operational Test Visualization (OTVIS) software developed by TRAC-WSMR was a critical tool. OTVIS allowed the observation of the NTC experiments in real-time and recorded entity data for post test playback. OTVIS was critical for post-NTC modeling by providing detailed event histories of movement, locations, and engagement data needed for replicating the AWE missions.

During the experiment portion of the AWE process, the brigade demonstrated battle by battle improvements in the use of digitization. Although actual unit performance was generally similar to non-digitized heavy brigade rotations, several observations were made. For example, improvements in the accuracy of locating the enemy, enhanced situational awareness, and the improved ability to move at night were examples of emerging trends that came from the exercise.

POST-EXPERIMENT (EXERCISE) MODELING PHASE

The post-experiment (exercise) analysis examined the "what ifs" observed during the live exercise. Each battle was reviewed for "digital opportunities." Digital opportunities are cases where situational awareness could allow commanders to make decisions much earlier than otherwise expected, set conditions more effectively for a decisive close fight, detect and decide much earlier to deliver fires and schedule close air support to arrive at the right time and place, concentrate combat power to overwhelm the enemy, improve tactical force protection, be agile and get inside the enemy's decision cycle, be audacious, and take calculated risks where warranted. (Commander, Operations Group, NTC, AWE Observations, 25 May 1997)

Three NTC missions were considered to have offered criteria that met the digital opportunities definition. These battles were the MTC, defense in sector, and hasty attack.

The first project was the post NTC brigade MTC. Capabilities learned from the first modeling phase were incorporated along with OTVIS data, subject matter experts (SME) comments, first hand analysts' observations, and multiple other sources. The end result was a CASTFOREM replication of the brigade's MTC.

The second project was a Janus/Appliqué exercise that allowed the brigade the opportunity to refight in constructive simulation the defense in sector mission. The goal was to assess the value added by digitization when fully exploited.

The third project was the Janus replication of the hasty attack. This scenario provided missed opportunity analysis and the integration of multiple combat multipliers. The brigade's plan was replayed with modifications focusing on using situational awareness information and improved coordination of battlefield operating systems.

The hasty attack is discussed in the next section. See TRAC-WSMR AWE reports for analysis of the brigade MTC and defense in sector.

POST-NTC HASTY ATTACK "525-5 Mission"

The hasty attack 525-5 mission was chosen because of brigade opportunities to fully integrate combat multipliers (e.g., close air support, artillery) that would enhance the massing of forces and battle tempo. If digitization improves the synchronization of battlefield operating systems, at decisive points, then changes in force effectiveness can be evaluated. Selected instances of potential digitization opportunities included enhanced coordination of TF 1-5 Infantry supporting the main attack, the TF 1-22 and TF 3-66 passage of lines in the Debman Pass complex, synchronization of combat power at the northern breach point, and coordination of maneuver among brigade units.

The hasty attack was modeled in Janus. To support the modeling effort experienced Janus gamers were employed. Data used in scenario development included sources such as OTVIS provided initial positions, maneuver routes, timing, and tactics. The gamers also used brigade After Action Reviews (AARs) where participants discussed their plans and tactics. Another advantage was that TRAC military players had first hand knowledge of the AWE gained by direct observation.

After the scenario was developed multiple Janus excursions were completed. The results served as the "base case" analytical data for comparison to the digitization case.

The digitization case was developed by providing the brigade commander and S-2 with improved blue situational awareness. This knowledge assisted the blue brigade commander in coordinating TFs 1-5 Infantry, 1-22 Infantry, and 3-66 Armor.

The hasty attack 525-5 mission occurred on 25 March 1997 with TF 1-22 Infantry leading flowed by TF 3-66 Armor. The brigade attacked one full strength motorized rifle battalion (MRB) supported by a reduced MRB, both in a hasty defense. The brigade's mission was to conduct a hasty attack and occupy positions in vicinity of Nelson Lake. TF 1-5 Infantry used helicopter and vehicle insertions at night into the Debman Pass complex vicinity the Goat Trail and Bruno Pass. TF 1-5 Infantry then infiltrated along the North Wall to support the brigade's main effort. TF 1-22 Infantry maneuvered into Brown Pass and encountered OPFOR ambush positions. The brigade stalled in the vicinity of Brown Pass. TF 3-66 Armor moved into the congestion and presented a lucrative target. The brigade suffered attrition by artillery and enemy aviation. The brigade soon realized that it was not near the primary MRB defensive belt. The brigade continued movement. The OPFOR used a persistent chemical strike to shape the brigade's movement. OPFOR long range anti-tank systems attrited the advancing blue force. When the brigade reached the designated breach site, it did not have sufficient combat power to accomplish their mission. The OPFOR was successful in preventing any penetration.

This scenario demonstrated that if available blue and red situational awareness was followed prior to entering the pass then the commanders could have controlled their movement and maintained a coordinated attack. Prior to the attack, brigade reconnaissance assets had identified most of the OPFOR battle positions and three of the four obstacle belts prior to the attack.

In the Janus digitized case, it was assumed that a coordinated blue advance would occur, along with non-degraded communications, and that situational awareness was available and used. In the digitized case, coordination of maneuver was a major factor in the brigade's success. OPFOR aviation and artillery were ineffective in Brown Pass because blue forces did not present a stationary target of opportunity. Also, improved positioning of blue Air Defense Artillery (e.g., Linebackers) restricted red aviation. With improved coordination between the TFs, artillery, blue aviation, and breach operations blue's tempo and massing of fires defeated the OPFOR.

Post-exercise modeling showed that improved situational awareness provided the commander time sensitive opportunities for decisive action unavailable to a commander in a non-digital environment. Extensive data collection, CASTFOREM improvements, and new modeling techniques allowed the assessment of the utility gained by digital technology on the battlefield.

LESSONS LEARNED

Several lessons were learned from the TF XXI AWE process. These lessons are examined from four perspectives: the analytical process, technology/C2, training, and the AWE.

The MEM/analytical methodology was a success. This process is resource intensive in time, money, and personnel. However, the value gained and the risk mitigated by making more informed decisions are large.

The strengths and weaknesses of C2 technology were seen at the TF XXI AWE. Technology does not solve all problems. However, technology does help situational awareness and digitization offers value added to force effectiveness. In particular, synchronization is enhanced by digitization. Also, the art of command, the ability to feel the battle, is still paramount. Fixating on a computer screen and waiting for perfect information does not win the battle.

Training in a new technology, given the time constraints on units, is a challenge. Training the soldier and building trust is important in the effective employment of information age technologies.

The AWE (exercise) was a single event, a sample size of one. Constructive simulations were able to expand this sample size from one too many. AWEs offer early interoperability testing, are intended to speed the acquisition process, and are less intrusive than traditional operational testing. However, the isolation of variables and the rigorous examination of the tested item is reduced.

CONCLUSION

The TF XXI AWE offered a clear vision of the potential for digitized ground forces. The proven winner is the power gained by increased situational awareness caused by digitization.

The AWE concept was a success. AWEs place new concepts into a rigorous evaluation short of actual combat operations. Additionally, the AWEs create an environment where initiatives are tested together.

The MEM methodology presented Army decision makers a clear view of the potential gained by digitization of the battlefield. This result allowed Army leaders a higher probability of making an informed decision as they plan the 21st century Army.

Evaluation of Battlefield Management Systems

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TNO is a modern Dutch, knowledge-based organisation providing services in the form of research, development and application of new technologies. TNO's knowledge finds immediate and practical use for all clients, both large and small, in the Netherlands and around the world. TNO provides most Dutch government departments with support in formulating policy, and undertakes projects to ensure that the policy works. The Dutch armed forces use the wide range of TNO services and the TNO defence research institutes are even referred to casually as the ministry of defence's in-house laboratory. Battlefield Management Systems (BMS) is one of the programs TNO is involved in.

Before this program will be described, it is important to define the meaning of BMS in the Netherlands. The picture below shows that the Command and Control-Infrastructure in the Netherlands comprises three groups of systems:

- ISIS, the integrated Staff Information System. This is the command, control, communication and information (C3I) system for the level brigade and above.
- BMS, the battlefield management system, the command and control systems for the level of battalion and below.
- SDA, the soldier digital assistant that provides the individual soldier with command and control information.

C2-programs in RNLA

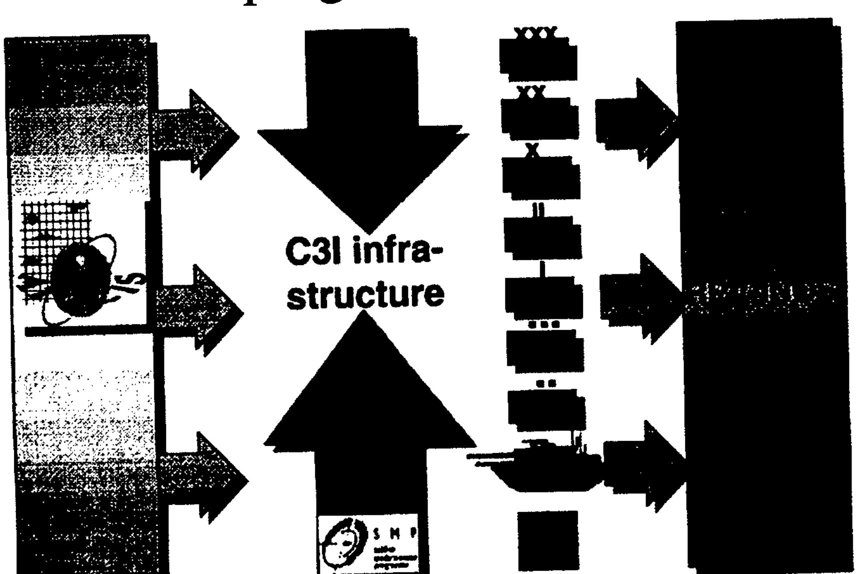

Figure 1: C2-programs in the Royal Netherlands Army

A BMS aims at reaching an optimal situation awareness while striving for maximal combat power, safety and endurance. Situation awareness can be defined as awareness of the current role and status related to friendly, enemy and neutral troops within the relevant part of the operational area. Situation awareness plays a major role in all decision processes.

The first phase of the Dutch Battlefield Management Research and Development program started in 1996 when the Royal Netherlands Army (RNLA) awarded TNO a contract to investigate the phenomenon BMS. The attention for BMS was coupled to the introduction of a new German-Dutch Reconnaissance Vehicle in 2001 (The Fennek). Although this platform will most likely be the first one with a fully integrated BMS, the BMS-study is not limited to this platform. The ultimate goal is that all operational units in the RNLA, starting with the reconnaissance, will have a BMS.

Among other things, the first phase led to a global list of functionality's and an identification of relevant developments in the international defence community. One of the outcomes of this study was the TNO-advise to evaluate a number of commercially available BMS's. It was advised by TNO to evaluate the systems in a laboratory environment.

The purpose of this evaluation was twofold: first of all it would have to assess the systems as a possible solution for a Dutch BMS; secondly, the evaluation would help to refine the requirements of the BMS obtained in the first phase.

The reason for an evaluation in a laboratory environment was:

- to save money compared to a complete field trial with the system
- get a strong focus on functionality and man-machine interface
- get a quick picture of the suitability of the available systems
- get a quick start with the specification of requirements

At the time of the decision, two systems were commercially of the shelf available: FINDERS® of GIAT Industries and DIFA of STN ATLAS. Both systems were evaluated in exactly the same way. This paper describes the approach that was taken during the evaluation and the methods that were used to describe the functional, technical and design features of the evaluated systems. We will not describe the actual conclusions with respect to the content.

One of the requirements for the Dutch BMS is the ability to exchange information with the higher level Command and Control system ISIS (Integrated Staff Information System). This system is built by the RNLA in co-operation with TNO and other industries. One way to accomplish this interoperability is by using components of ISIS and adapt the functionality and the man machine interface to the BMS-level. For this reason ISIS was the third system to be evaluated. The evaluation of ISIS slightly differed from the evaluation of FINDERS® and DIFA, due to the fact that ISIS is not a BMS and only components of this systems might be used. The evaluation of FINDERS took place in December 1996, DIFA was evaluated in March 1997. ISIS was subjected to our tests at the end of 1997.

The evaluation comprised 5 blocks: Training, Functional evaluation, Technical Evaluation, Scenario Evaluation and Discussions. In order to cover military operational, human factor as well as technical aspects of the evaluated BMS, a team has been set up consisting of military reconnaissance and main battle tank experts of the RNLA, human factors experts and technical experts. The total team comprised 7 people and was constantly supported by the suppliers. The combination of the people in this team assured that all relevant aspects of the system would be given a chance. Neither of the companies ever subjected their systems to a team like this.

The evaluation has been performed on behalf of and in close co-operation with the BMS-projectteam of the RNLA. Representatives of this group attended several sessions of the evaluation to give a valuable contribution from the operational context to the experimental sessions and discussions.

Below, each of the 5 blocks of the evaluation will be described. After these 5 blocks, there is a section which describes the way the results were presented and a section with the conclusions and recommendations.

Training

The training block was incorporated to get used to the system and to get an overview of the functions offered by the system. The time needed to reach this goal was three days for each system. At the end of the training session, each participator should have a clear understanding of the basic concept of the system and should be able to find the most important functions without assistance. In this way the functional and scenario evaluation will not be hindered by lack of knowledge of the system.

This block also included the set-up of a function overview that could be used as the guideline to execute the functional evaluation. The main question for this set-up was how the functional evaluation can be done in a structured manner that results in a complete overview of the functions and gives a detailed view of how the functions can support the reconnaissance task.

In general one can take two approaches. One can take the system with its function as the starting point or one can take the soldier with it's task as the point of departure. With the first functional approach you evaluate a function and try to find out which tasks are supported by this function. You will probably find out that there are functions that do not support any tasks. With the second task oriented approach you evaluate a task and try to find out which functions can support this task. Both approaches have clear advantages and disadvantages. The functional approach leads to a very thorough understanding of the functions, but will perhaps fail in delivering a good understanding about what this function means for the reconnaissance tasks. The task oriented approach will solve this problem, but might split up the evaluation of functions in to much pieces.

The solution for this dilemma is a simplified C3I-model that divides the functions of the BMS into four groups of logically related functions. The groups are *Command, Control, Communication* and *Information*. Each group consists of functions or sets of functions that are logically related in the sense that they are usually performed together.

Below you will find the simplified C3I-model.

<table>
<tr><td>COMMAND
• Receive / Check / Interpret order
• Compose / Send order
• Adapt / Send order
• Send feedback information
• Receive feedback information</td><td>COMMUNICATION
• Initialise / Manage communication network
• Know what you sent / received / saved
• Know to whom and from whom messages were send and received
• Manage your mailboxes</td></tr>
<tr><td>CONTROL
• Check equipment status
• Compose / Send status report
• Receive / Check / Interpret status report
• Compose / Send request for fire support
• Receive / Check / Interpret request for fire support
• Compose / Send request for logistic support
• Receive / Check / Interpret request for fire support
• Plan / Plot / Control Route</td><td>INFORMATION (SITUATIONAL AWARENESS)
• Report observations
• Compose / Send alerts
• Receive / Check / Interpret alerts
• Compose / Send situation reports
• Receive / Check / Interpret situation reports
• Monitor friendly/hostile positions / movements / actions
• Monitor environment (geogr., meteo., NBC, ...)</td></tr>
</table>

This simplified model is based on the command & control functions that we currently find in the available BMS's.

Functional evaluation

During the functional evaluation we tested the functions separately or in logically related groups in accordance with the simplified C3I-model. The goal of this block is to get a detailed description of a representative or complete selection of the functions offered by the BMS's. This was used to refine the global functional requirements that were obtained in the first phase of the program as well as a means to come to a conclusion about the suitability of the evaluated BMS as a basis for a Dutch reconnaissance BMS. The functional evaluation took two days.

Two forms were used for the functional evaluation. One that has to be filled in for each evaluated function and one that has to be filled in once after completing all functional evaluations. The first form basically specifies the strong and weak points of the functions in relation to the reconnaissance task these functions were meant for. It also contains an overall rating that the user can assign to the (group of) function(s). Each participant had to fill in the form. In this way we got the expert vision of technical, human factors and operational military experts. You will find this form in Appendix A.

The second form gave the evaluators the opportunity to specify some of the more general problems they experienced while using the system. This list is based on a method of Ravden and Johnson [1]. This method is used for software systems in general and is in particular useful for software systems that have to be used in military environments that are time critical and where the main job is not using the computer but fulfilling some kind of military operation under mostly difficult circumstances. You will find this form in Appendix B.

There are several aspects that are not function-specific and/or did not fit in the evaluation of a specific evaluation step. An example of this is map scrolling. We paid special attention to these points during the second day of the function evaluation.

Scenario Evaluation

During the evaluation of the functionality, there was a strong focus on functions or sets of functions. Although this evaluation was done with the reconnaissance tasks in mind, there was a risk that information would be missed about the support that the BMS gives the reconnaissance unit during the preparation and execution of a reconnaissance mission. For instance, during the functional evaluation, not much information about the situation awareness was acquired, like the visibility of contact alerts that were received. This is because every step in the function evaluation was planned in advance and lacked the element of surprise.

For this reason, we designed a scenario of a reconnaissance mission that could be played during the evaluation. Of course, one had to take into account the restrictions of a laboratory environment without a real (or computer simulated) enemy. Nevertheless, we expected to get information about the operational usefulness of the system during this evaluation step.

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[1] Ravden, S. and Johnson, G. Evaluating usability of human-computer interfaces: a practical method. Ellis Horwood Limited, Chichester, England. ISBN 0-7458-0614-7 (1989)

In order to get a realistic script, we designed the scenario in co-operation with military reconnaissance experts. The mission used in this scenario was a reconnaissance of an area with roughly a width of 10 km and a depth of 20 km. The mission was part of a brigade's intended advance to contact. We divided the mission in a mission-preparation phase and a mission-execution phase. The roles of the platoon commander(PC), group commander(GC), vehicle commander(VC) and squadron commander (SC) were played. With the representation of these roles, a scenario could be designed that pays attention to different communication and co-ordination aspects, situation awareness and the information needs of different command levels.

The events that occurred during the scenario were simulated by cards. There is a set of cards for each player. The cards are handed to the player by the scenario leader. A card contains all the necessary information about the event that took place. So, instead of the first contact with an enemy vehicle, the player got a card describing this event with information like position, direction of movement and actions of the enemy that was spotted.

In order to avoid 'unnatural' contact between the players, the players were separated from each other by a wooden partition. The only way to communicate with each other was via the BMS or via the voice radio. Of course this could only take place in accordance with the appropriate protocols. For instance, if a certain situation in the scenario enforced a radio silence periods, no voice communication was possible. Without this restriction the participants would have been able to communicate with each other about system specific items that would normally not occur like 'did you see the message I send you' or 'you should use the right button to perform this specific action'. This kind of communication would infuence the reliability of the results of the evaluation.

A complete description of the scenario can be found in Appendix C. The playing of this scenario occupied one full day and was attended by the complete evaluation team as well as three engineers from the company that delivered the BMS. The tasks of the scenario were divided into four scenes. For each scene the evaluators had to fill in one form as displayed in Appendix D.

Technical evaluation

During the technical evaluation we looked at all kinds of technical issues like (software) robustness, backup and recovery and the connection to the combat net radio's, including the protocols that were used to send and receive messages. Most of the technical evaluation was done by discussing about it. Only a few tests were performed like switching of the system (in several ways, for instance by unplugging all kind of cables) and recovering form this event. We did not pay attention to hardware robustness, since this can only be done in a real environment.

The discussions were used to present our first impressions and to get more insight in all kind of choices that were made by the supplier. Also, these discussions were used to get more information about the abilities of the system to exchange information with higher level C3I-systems.

Presenting the results

The results of the evaluation were presented to the RNLA in a report. An important part of this which is interesting in this context is the part where the results of the functional and scenario evaluation is presented. For evaluating the data obtained from the functional and scenario evaluation, a framework of well-known Human-Computer interaction software ergonomics criteria as set out in Ravden & Johnson [2] was used. These criteria are visual clarity, consistency, compatibility, informative feedback, explicitness, appropriate and missing functionality, flexibility and control, error prevention and correction, and user guidance and support. The data have been examined from all these viewpoints. The resulting information has been organised along six more task-oriented lines. The main findings of the computer-user interface evaluation have been summarised in tables like the one in Appendix E..

There are six tables for six categories. The tables give a very quick impression of the evaluation results and also gives the possibility to compare systems with each other.

The first category of findings concerns system configuration and control of the system (the example given above), the second map presentation and functions, the third tactical information presented on the overlays, and in the fourth category communication issues are discussed. The fifth section concerns automatic updating functions. In the sixth section a rating of the input devices can be found, and the last section contains information on the display. These findings must be interpreted within the tasks and functions that could be carried out with the system in a laboratory setting, and cannot be generalised to the fully operable system. Although the set-up allowed the evaluation of planning and message handling functions, the evaluation of situation awareness definitely suffered from the lack of a real setting with the BMS connected to platforms and possibly a higher-echelon C2 system.

In the report, the summary of findings of the user and scenario evaluation is followed by a very detailed descriptions of all the results. With a lot of examples, the strong and weak points of the system are described.

Conclusions and recommendations

The evaluation process of the BMS's has given insight in the potential applicability of the system for the Dutch reconnaissance units and the Fennek in particular. It also resulted in obtaining experiences in order to refine the functionality's as expressed earlier by the Dutch Army Staff. However this evaluation was performed under the restrictions of a laboratory environment and therefore did not touch operational and sensor integration aspects.

Based on the results of the evaluations a choice has been made to use components of the Dutch ISIS-system and Commercial of the Shelf components for the design and implementation of a pilot BMS system. The goal of this pilot system is to come to the final functional and technical requirements of a Dutch BMS system. In the first version of this pilot system the recommendations of the laboratory evaluation will be processed. The intention is to reach this goal by organising a number of field trials and involve the end-user in these field trials to refine the requirements in a number of steps. After each experiment the pilot system will be adapted to incorporate the new requirements that are obtained. The experiments will begin on the scale of a platoon and end on a battalion scale. All units used for the experiments will be reconnaissance units. However the pilot system will consist of a generic part that can be used for all kind of units and a specific reconnaissance part. Beside this, each kind of platform that is involved can have a different manifestation.

After the pilot phase, the industry will have to be involved to build an operational version of the BMS. The pilot phase only serves as a vehicle to get the final requirements.

In addition to the pilot project, a modelling and simulation path has been started to evaluate sensor integration aspects and ergonomic aspects of the use of a BMS in the Fennek vehicle. TNO has taken preliminary steps with respect to the facilities in her laboratory to accommodate such a study.

During the coming year TNO will be heavily involved in the pilot project and the modelling and simulation path. Both projects will be performed in close co-operation with the BMS-projectteam of the RNLA.

Appendix A: FUNCTION EVALUATION FORM

USER NUMBER	
TASK DESCRIPTION	
TASK PRIORITIES	

QUESTION NUMBER	**COMMENTS**

STRONG POINTS	**WEAK POINTS**

MISSING FUNCTIONALITY

SYSTEM RATING				
unsatisfactory	moderately unsatisfactory	neutral	moderately satisfactory	satisfactory

Appendix B: SYSTEM USABILITY QUESTIONAIRE FORM

Usability category	Problems		
	none	minor	major
1. Working out how to use the system			
2. Lack of guidance on how to use the system			
3. Poor system documentation			
4. Understanding how to carry out the tasks			
5. Knowing what to do next			
6. Understanding how the information on the screen relates to what you are doing			
7. Finding the information you want			
8. Information which is difficult to read clearly			
9. Too many colours on the screen			
10. Colours which are difficult to look at for any length of time			
11. An inflexible, rigid system structure			
12. An inflexible HELP (guidance) facility			
13. Losing track of where you are in the system or of what you are doing or have done			
14. Having to remember too much information while carrying out a task			
15. System response times that are too quick for you to understand what is going on			
16. Information which does not stay on the screen long enough for you to read it			
17. System response times that are too slow			
18. Unexpected actions by the system			
19. An input device which is difficult or awkward to use			
20. Knowing where or how to input information			
21. Having to spend too much time inputting information			
22. Having to be careful in order to avoid errors			
23. Working out how to correct errors			
24. Having to spend too much time correcting errors			
25. Having to carry out the same type of activity in different ways			

Appendix C: The complete scenario description

A Dutch reconnaissance platoon consists of three groups of two vehicles (A/B, C/D, E/F) and one commander vehicle (R) with the Platoon Commander (PC). The groups are named after its first vehicle (A, C and E) and are leaded by a Group Commander (GC). The individual vehicles are leaded by a Vehicle Commander (VC). The platoons are part of a squadron with a Squadron Leader (SC). In this case, the squadron will be part of a brigade. This type of squadron consist of 2 reconnaissance platoons and one platoon of skirmishers (First, Second and Third platoon).

The mission used in this scenario will be a reconnaissance of an area with roughly a width of 20 km and a depth of 30 km, east of the city Amersfoort. The reconnaissance will be executed by the first platoon and the second platoon, side-by-side. (The second platoon operates south of the first platoon). The reconnaissance mission will be part of an intended advance to contact a brigade. The goal of the mission is to make sure that the area is clean for the advance of contact. Of course, a number of observation posts will be set up at the utmost limit of the reconnaissance area.

We will divide the mission in a mission-preparation phase and a mission-execution phase. The role of the PC, GC and VC will be played. Occasionally, the role of an SC will be played While running the scenario, we will regularly pause to evaluate.

MISSION PREPARATION (SCENE I)

NR	FROM	TO	ACTION	ACTION BY SCENARIO LEADER
P1	SC	R	distribute KVPOG[2] by MIDAT.	Load KVPOG in MIDAT.
P2	R	A/C	distribute KVPOG.	
P3	SC	R	distribute order by MIDAT.	Load squadron plan in MIDAT.
P4	SC	R	Verbally explain paragraph 3 (combat plan) of NATO standard order.	Explain combat plan verbally.
P5	R	A/C	send NATO standard order.	-
P6	R	A/C	Verbally explain paragraph 3 (combat plan) of NATO standard order.	-
P7	R	A/C	Ask for Function Control 1 (FUCO-1).	Give CARD-R1.
P8	A/C	R	Pass result of FUCO-1.	-
P9	A/C	R	Pass detailed group plan.	-
P10	-	-	Reject detailed group plan of C.	Give CARD-R2 with info about rejection.
P11	R	C	Pass changes of detail plan of C.	-
P12	SC	R	Pass latest information about enemy and terrain.	Load latest enemy/terrain info in MIDAT.
P13	R	A/C	Pass latest information about enemy and terrain.	
P14	-	-	Fill in evaluation form	Give evaluation form to A, C and R

[2] KVPOG is a Dutch abbreviation for: coming action, the movement, expected time and place of orderreceiving, The higher command level and the level of combat readiness. Consider this as a warning order.

MISSION EXECUTION (SCENE II)

NR	FROM	TO	ACTION	ACTION BY SCENARIO LEADER
E1	-	-	R, A and C in start position.	Move Vehicles to R1, A1, C1.
E2	C	R	Arrived at object, perform dismounted reconnaissance.	Specify by CARD-C1. Vehicles at R1, A1, C1.
E3	-	-	-	Move Vehicle to R1, A2, C2.
E4	C	R	No peculiarities at object.	Give CARD-C2.
E5	A	R	Enemy alert (VIJ-1).	• Location (VIJ-1) by simulation. • Kind of enemy (VIJ-1) by CARD-A1. Vehicles at R1, A2, C2.
E6	A	R	Artillery request on enemy (VIJ-1).	Give CARD-A2.
E7	A	R	Cannot reach Southside of village.	Give CARD-A3.
E8	R	C	Reco. Southside of village.	Give CARD-R3.
E9	-	-	Artillery fire destroys enemy (VIJ-1).	Give CARD-A4.
E10	-	-	-	Move Vehicle to R2, A2, C3.
E11	A	R	Passing results of Artillery Fire.	Give CARD-A5.
E12	-	-	-	Move Vehicles to R2, A2, C4.
E13	C	R	Southside village free of enemy.	Vehicles at R2, A2, C4.
E14	-	-	Fill in evaluation form	Give evaluation form to A, C and R

MISSION EXECUTION (SCENE III)

NR	FROM	TO	ACTION	ACTION BY SCENARIO LEADER
E15	R	A/C	Continue with mission on original route.	Give CARD-R4.
E16	-	-	-	Move Vehicles to R3, A3, C5.
E17	-	-	-	Move Vehicles to R3, A4, C6.
E18	A	R	Enemy alert (VIJ-2).	• Location (VIJ-2) by simulation. • Kind of enemy (VIJ-2) by CARD-A6.
E19	A	R	Pass information about minefield.	Give CARD-A7 (location and area).
E20	-	-	-	Move vehicles to R3, A4, C6.
E21	C	R	Arrived at object, perform dismounted reconnaissance.	Give CARD-C3.
E22	-	-	-	Move Vehicles to R3, A4, C7.
E23	C	R	No peculiarities at object.	Give CARD-C4.
E24	-	-	Fill in evaluation form	Give evaluation form to A, C and R

MISSION EXECUTION (SCENE IV)

NR	FROM	TO	ACTION	ACTION BY SCENARIO LEADER
E25	R	A	A has to use object of C to continue original route.	Give CARD-R5.
E26	-	-	-	Move Vehicles to R4,A5, C8.
E27	C	R	• Vehicle D hit by enemy and is in fire. • Enemy (VIJ-3) location unknown.	Give CARD-C4.
E28	R	C	• First aid to crew of Vehicle D. • Determine enemy (VIJ-3) location.	Give CARD-R6.
E29	R	A	Try to get information about enemy (VIJ-3).	Give CARD-R7.
E30	C	R	• Vehicle D cannot be used anymore. • Driver most likely killed / Commander seriously injured, urgently needs medical help. • Enemy (VIJ-3) location unknown.	Give CARD-C5.
E31	-	-	-	Move Vehicles to R4, A6, C8.
E32	A	R	NBC-1 detection alarm.	Give CARD-A8.
E33	R	A	Perform NBC detection.	Give CARD-R8.
E34	A	R	Send NBC-3 (detection report).	Give CARD-A9.
E35	-	-	-	Move Vehicles to R3, A6, C8.
E36	R	A/C	Pass: had consultation with SC. Enemy pressure to big. Take into account the arrangement of observation posts on westside of A-30 (highway). Observation sectors will follow.	Give CARD-R9.
E37	R	A/C	Pass observation sectors.	Give CARD-R10.
E38	-	-	-	Move Vehicles to R4, A4, C6.
E39	A/C	R	Pass actual observation sectors.	Give CARD-A10 and CARD-C6.
E40	-	-	Fill in evaluation form	Give evaluation form to A, C and R

Appendix D: SCENARIO EVALUATION FORM

DATE	
MISSION PHASE	
MISSION STEPS	
ROLE	
OPERATIONAL TASK	
FUNCTIONALITY / SUPPORT REGARDED AS ADEQUATE	
FUNCTIONALITY / SUPPORT THAT NEED IMPROVEMENT / CUSTOMIZATION	
BMS FUNCTIONALITY AND SUPPORT THAT IS MISSING	

SYSTEM RATING				
very unsatisfactory	moderately unsatisfactory	neutral	moderately satisfactory	very satisfactory

Appendix E: Main findings of System Configuration and Control

category	rating	remarks
System Configuration and Control		
Functional compatibility with RNLA reconnaissance tasks		
Transparency: ease of learning, understanding and using		
Suitability of system for planning and action preparation		
Suitability of system for action execution		
Access to system functions and their organisation along function keys and menus		
Guidance of user		
Indication of settings, state, messages and warnings		
System response times		
Back-up facilities for information recovery		
Saving of selected information		
Query capability		
Printing facilities		

FLIGHT OPTIMIZATION IN RECONNAISSANCE MISSIONS

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ABSTRACT

There are multiple surface units (targets) detected earlier by radars in a particular sea area. An observer (an air vehicle) will try to identify those moving targets by passing them within the specified identification range of its sensors to maximize the flow rate of information coming from identification. A Branch and Bound algorithm is proposed to optimize the flight pattern of the observer.

1. INTRODUCTION

The importance of intelligence can not be overstated in maritime warfare. Deployed Naval forces have a continuous need for information gathering which is achieved, in general, through missions to detect, investigate, identify, localize and report the details of enemy naval units. Such missions are regarded as surveillance/reconnaissance and have related operations such as : patrol, search, identification, etc.

This study is on an identification operation to be conducted by a single air vehicle against multiple surface units. The air vehicle may be a fixed wing aircraft, a helicopter or an UAV (Unmanned Air Vehicle). Throughout the term ***target(s)*** will be used to denote the surface unit(s) to be identified, and ***observer*** shall stand for the air vehicle.

It is assumed that other friendly forces have conducted proper operations and detected the existence and the prospective trajectories of some surface units on a particular sea area. However, status (friend or foe), class and type of the units are to be identified. The observer will follow a definite flight path to visit (and thereby identify) the targets. As targets are idenfied, an information flow is realized during this operation. The purpose is assumed to be achieving as high an information flow rate as possible within prescribed time limits.

Search Theory is one of the oldest areas of Operations Research. Pioneered by the works of Koopman[7,8,9] and after several decades of subsequent development, search problems are still in the same form: a single target is lost and the problem is to find it effectively with fixed resources. Targets are assumed either stationary with a

known probability distribution of their location or, moving with a known probability distribution of the paths made up of cells they will occupy sequentially. Moving target problems are handled with or without reaction of the target to the searcher.

Stone[13] presents a comprehensive study of stationary target problems. Moving target problems with no target reaction are handled as optimal search density problems in which total search effort can be divided among the cells in arbitrary proportions as in Brown[2] or, as optimal searcher path problems in which the search effort can not be divided and the next cell to be visited has to be one of the neighbouring cells as in Steward[12], Eagle[5] and Eagle et al [6]. Brown showed that search density problems reduces to solving a sequence of stationary target problems. Washburn[14] developed an algorithm which generalizes Brown's approach to apply to wider class of objectives than maximizing detection probability. Steward proposed a branch and bound solution to the searcher path problem. Game theoretic approaches are found for problems involving target reaction. Baston and Bostock [1] developed a two-person zero sum game in which a searcher with limited ammunation wishes to destroy a mobile hider. Charnes and Schroeder [3], Danskin[4] and Washburn[14] defined search evasion games related to anti-submarine warfare.

Kuwahara[10] developed a simulation model which deals with an antisubmarine warfare operation conducted by an aircraft. Reiss[11] proposed an integrated simulation model of search and identification operations. He considered a large rectangular sea area crossed by a number of ships and searcher aircraft which performed visual identification of ships detected by its on-board radar. The problem was stated as finding the goemetrical parameters of a given basic search pattern from which stochastic deviations took place. The objective is the minimization of flight time for a given area or maximizing the swept area within prescribed time limits.

2. PROBLEM DEFINITION

Assume that there are N targets detected earlier by the radars in a particular sea area. Thereby, it is also assumed that targets move at constant speeds over fixed courses known to the observer. The flight path of the observer consists of a sequence of target ***identification points*** ordered in time. Targets are assumed not to react to the observer as it visits their vicinity. The observer is also assumed to fly at constant ground speed at a suitable constant altitude, capable of intantenous changes in its course.

The target is taken as identified when the observer passes it within the specified ***identification range*** (IDRNG). Hence, an imaginary ***identification circle*** (IDCRL) with radius IDRNG is formed around every moving target. As the observer enters into this circle or even passes along a tangent to this circle, the target is taken to be identified with subsequent instantenous reporting to follow.

No closed region to flight is assumed for the observer. Climatic conditions are supposed to be taken into account in determining the range of visibility (hence the preset value of IDRNG).

The problem is solved on two dimensional continuous space and discrete time steps of identical time duration (DURTN). Discrete time assumption may cause divergence from reality in motion analysis. However, it is possible to make a reasonable approximation by reducing step durations.

In the following, we adopt the notation used in Koopman[7]:

2.1 Suitable Courses

Any course of the observer that is designed to identify a particular target at a given position located inside its IDCRL in that period constitutes a suitable course for the given target and identification point in time . Suppose **U** and **V** denote the velocity vectors on the two dimensional space of a given target and, the observer, respectively. Then,

W = The reletive velocity vector of the observer with respect to the target

$$\mathbf{W} = \mathbf{V} - \mathbf{U}$$

Let ϕ denote the observer's track angle measured from **V** to **U** in the counter-clockwise direction. Figure 1 depicts the true and relative velocity vectors and the track angle ϕ

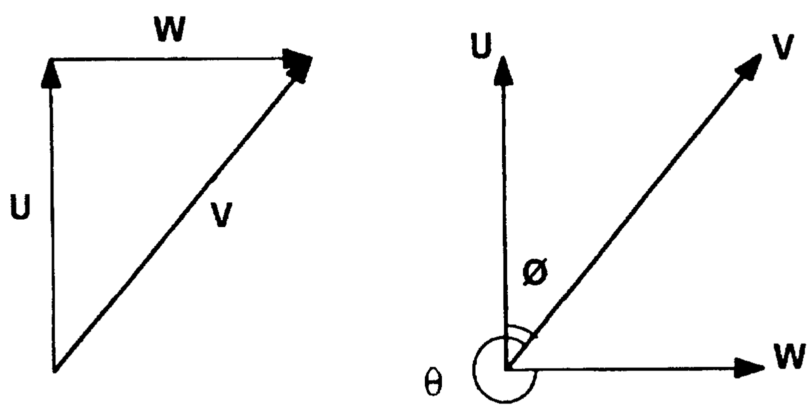


Figure 1. True and Relative Velocities

Let us define,

$\mathbf{X}_t$ = location of the target at step t, t = 0,1,2,3,....,T

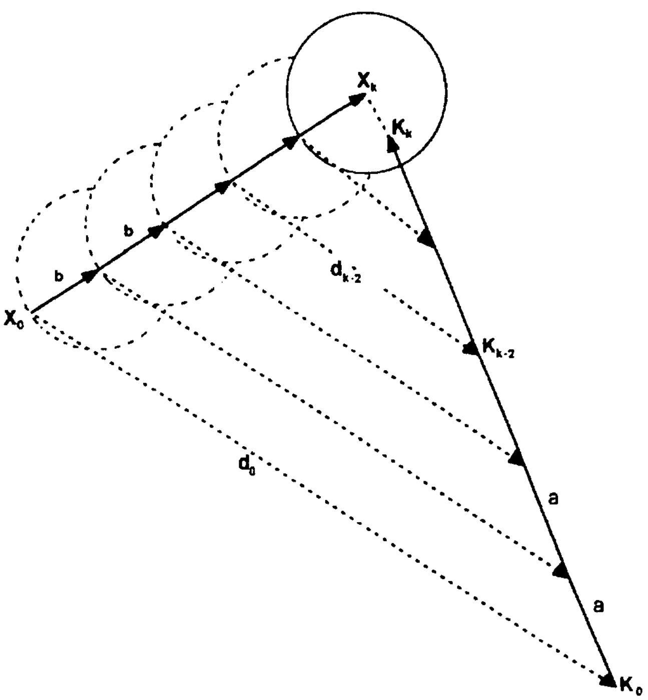
$\mathbf{K}_t$ = location of the observer at step t, t = 0,1,2,3,....,T

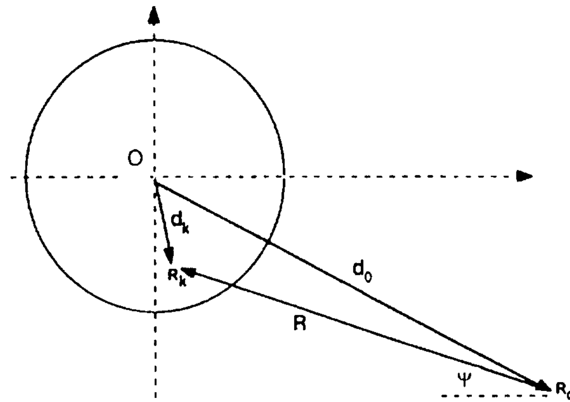
$\mathbf{d}_t$ = position vector of the observer wrt the target at step t, t = 0,1,2,3,...,T

Hence $\mathbf{d}_t = \mathbf{K}_t - \mathbf{X}_t$

Assuming that it is possible to identify the target in ***p*** steps, it can be followed from Figure 2 that it is required for $\mathbf{d}_0$ to change into $\mathbf{d}_k$ through **k** time steps, for the identification to occur at the required point. The difference between $\mathbf{d}_0$ and $\mathbf{d}_k$ defines desired motion vector **R** of the observer w.r.t the target.

Hence $\mathbf{R} = \mathbf{d}_0 - \mathbf{d}_k$





R_0 :Initial position of the observer relative to the target. It is the transformation of K_0 into new coordinate system
R_k : Position of the observer relative to the target at step t . It is the transformation of K_k
R : Motion vector of the observer relative to the target
ψ :**The angle which represents the direction of the R,** measured from **R** to the horizantal axis in the counter-clockwise direction

(b)

Figure 2. Illustration of Desired (a) Absolute and (b) Relative Motions

The desired absolute (true) velocity vector of the observer, **V**, for the suitable path, can now be found by the help of known relative motion vector, **R**, and the target velocity vector, **U.** This is demonstrated in Figure 3. Vector **V** points to the point of intersection of the relative motion vector **R** and the circle with radius |**V**| drawn from the head of the target velocity vector **U**. The relative velocity vector , **W**, can also be derived straightaway.

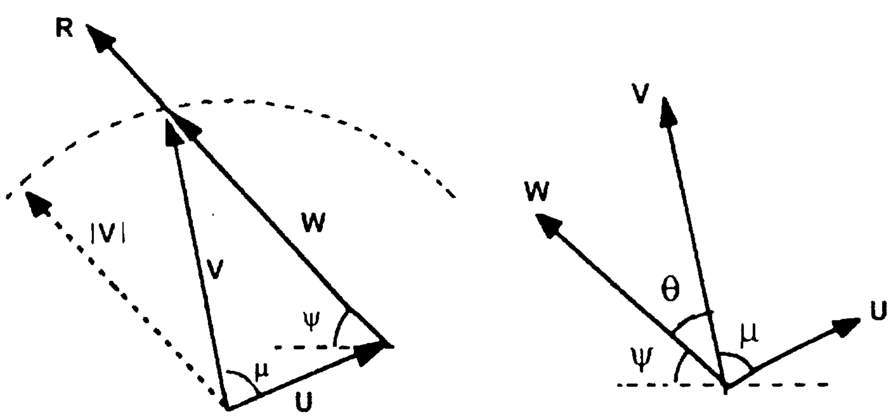


Figure 3. Finding the Desired Velocity Vector of the Observer

The number of steps required to identify the target ,**k**, can be found such that magnitude of relative velocity, |**W**| , covers the relative distance , |**R**| . Let RT denote real time required to make this motion. That is,

$$RT = \frac{|R|}{|W|}$$

Since discrete time is assumed, k is the smallest integer larger than or equal to RT. That is,

$$k=Int(RT) \geq RT$$

2.2 Extreme Courses

Given a target and the number of time periods to identify it, all suitable courses are included in a cone defined by *extreme courses.* Such cones can be defined using tangents drawn from the relative position of the observer to the "to be " IDCRL as many number of periods later as given. Extreme courses will then be given by defining absolute velocity vectors of the observer to yield such relative motion vectors. Exactly two tangents can be defined from any point to a circle unless the point is on the circumference. Hence two extreme courses can be generated as shown in Figure 4.

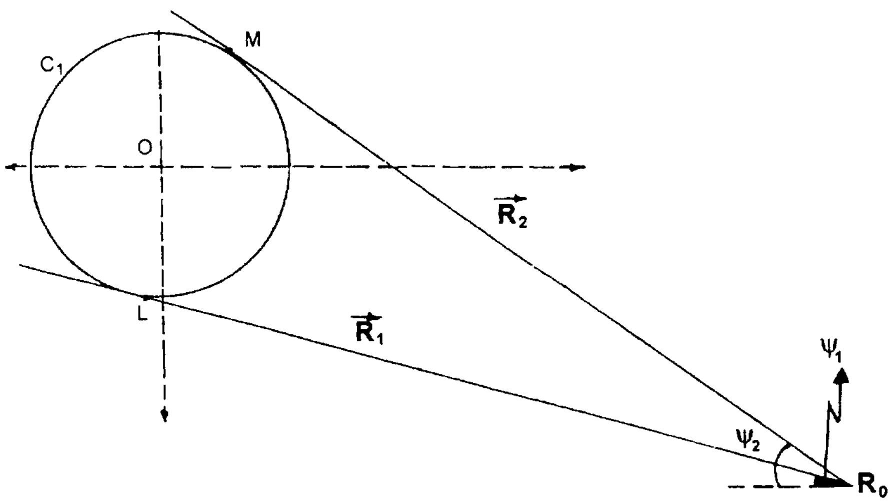


Figure 4. Extreme directions and Courses

2.3 Identification in Minimum Time

Normally, it is desired for the observer to identify a target as soon as possible- although this is not necessarily the case on an "optimal" course as will be seen later- . Consider concentric circles with radii k |**V**|, k = 0,1,2,3,... drawn around the observer; and the target's identification circles ($IDCRL_k$) progressing in discrete steps, **k**, as it moves along its course. Identification in minumum time occurs for the least value of k for which the concentric circle of radius k |**V**| intersects $IDCRL_k$.

Let us denote this particular value of k by k^*. Identification in minimum time depicted in Figure 5.

The shortest distance to be covered by the observer is given by the line joining the target and the "to be" location of the target at k^*. This defines a suitable course

directed towards the intersection of the circumference of $IDCRL_{k^*}$ and the straight line joining the observer's initial location and the target's location at k^*. This occurs at point B in Figure 5.

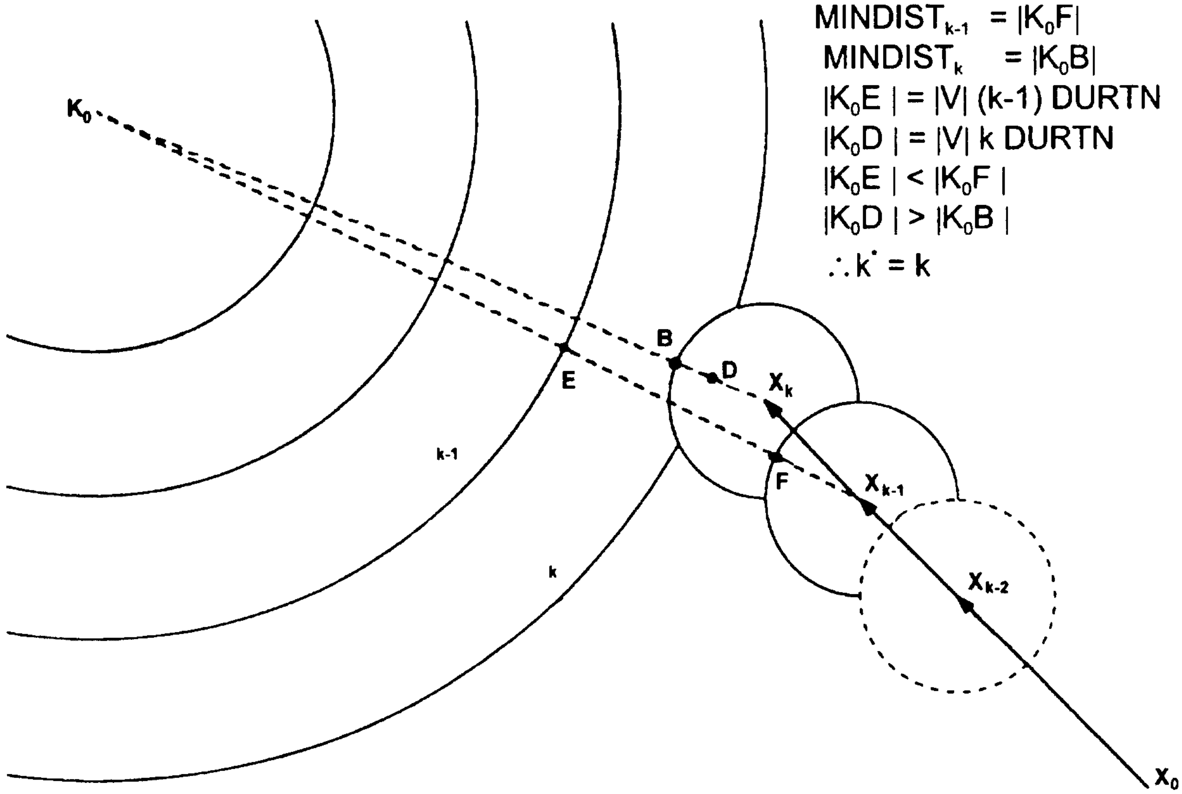


Figure 5. Occurance of Minumum Identification Time

The geometry of the minumum identification time can be followed in Figure 6. The observer has to cover at least a distance of (c - IDRNG) along KX_k. Hence

$$k^* = Min\left\{ k:\ \ k|V| \geq c - \ IDRNG \right\}$$

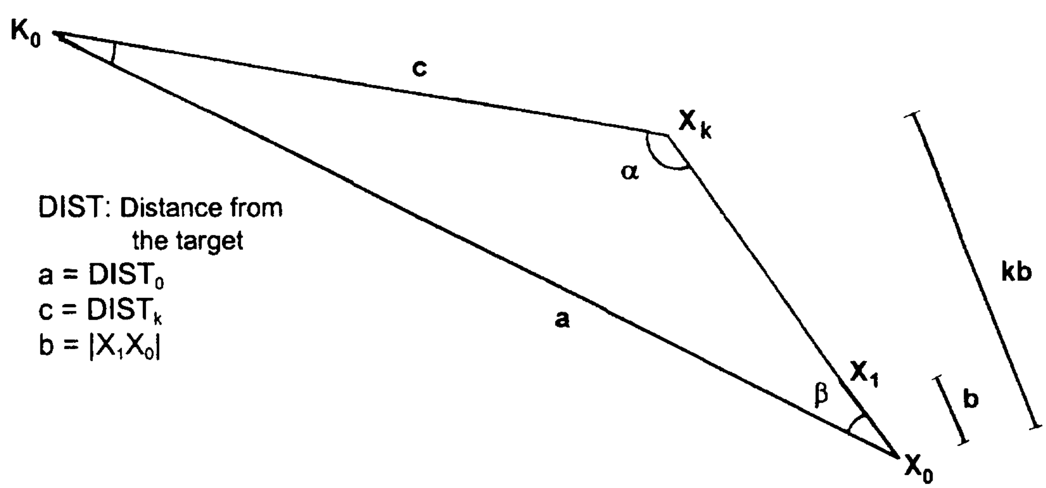


Figure 6. Distance Relations for Identification in Minumum Time

Considering the triangle X_0KX_k in Figure 6 and the law of cosines to substitute for c, above relation becomes:

$$k^* = Min\left\{k:\ k|V| + IDRNG \geq \sqrt{a^2 + k^2|U|^2 - 2k|U|\ a\ \cos\beta}\ \right\}$$

or, taking the squares of both sides of the constraint and manipulating it;

$$k^* = Min\left\{k:\ (|V|^2 - |U|^2)k^2 + 2(|V|\ IDRNG + a|U|\cos\beta\,)k \geq a^2 - IDRNG^2\ \right\}$$

Since **|V|**, **|U|**, **IDRNG**, **a** and **cos**β are known constants, the following can be defined in their terms:

$Z_1 = |\mathbf{V}|^2 - |\mathbf{U}|^2$;
$Z_2 = 2\,(\,|\mathbf{V}|\ IDRNG\ + a\,|\mathbf{U}|\cos\beta$;
$Z_3 = a^2 - IDRNG^2$;

and the relation becomes:

$$k^* = \text{Min}\{\,Z_1 k^2 + Z_2 k - Z_3 \geq 0\,\}$$

and therefore , k^* can be calculated using the roots of the quadratic equation

$$Z_1 k^2 + Z_2 k - Z_3 = 0$$

Due to the nature of the constants, the roots are guaranteed to be real valued. They both may be positive depending on the sign of constant Z_2. However, one root is guaranteed to be positive.

Since an integer step count is needed for k^*,

$$k^* = \text{Min}\{\,k:\ \text{Int}(k_1)\ \text{ or }\ \text{Int}(k_2)\ \text{ and }\ k \geq 0\,\}$$

where k_1 and k_2 are the roots of above quadratic equation. If $k^* = k_1$ (or k_2) then there is only one suitable course for the minumum time for identification. If $k^* > k_1$ (or k_2) then infinetely many suitable courses exist for the minumum time for identification.

It is also possible to extract the track angle ϕ from Figure 6 using the law of cosines and setting $k = \text{Min}\{\,k_1, k_2\,\} \geq 0$:

$$\phi = Arc\cos\left(\frac{k^2|U|^2 + c^2 - a^2}{2\,k|V|c}\right)$$

using $c^2 = a^2 + k^2|U|^2 - 2\,a\,k|U|\cos\beta$ to substitude in, one can get ϕ in terms of the initial displacement **a,** target speed $|\mathbf{U}|$ and the angle β:

$$\phi = Arc\cos\left(\frac{k^2|U| - a\ Cos\beta}{\sqrt{a^2 + k^2|U|^2 - 2\,a\,k|U|\,Cos\beta}}\right)$$

2.4 Performance Criterion

Information flow will be realized at discrete steps in time according to the formulation. As a target is identified, a message is transmitted immediately, generating a "unit" of information. The purpose of "as high an information flow rate as possible" can be achieved by maximizing the average accumulated number of units of information.

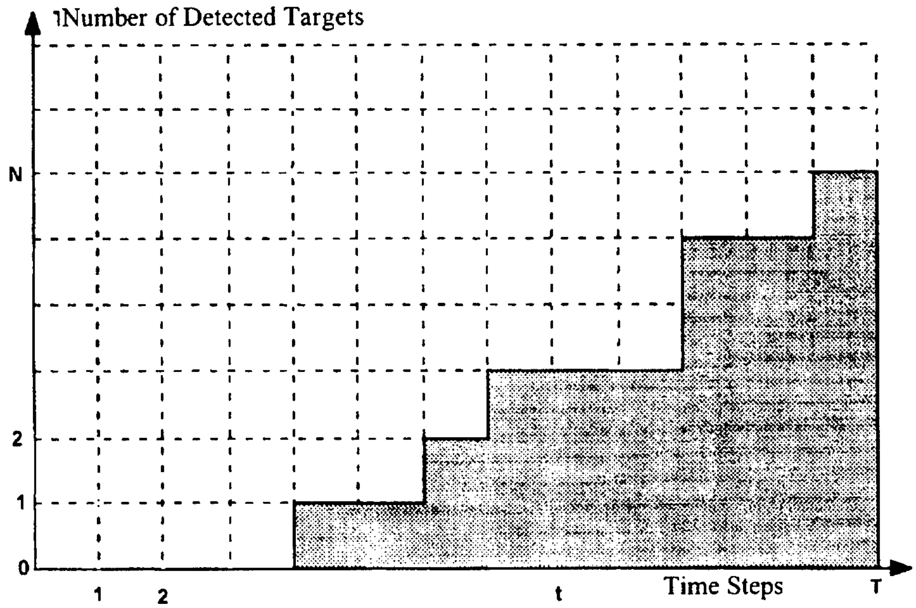


Figure 7. Accumulation of Information

Let n_t donete the number of accumulated number of identified targets (or units of information) at step t. Then the mean accumulated units of information to be maximized can be found as:

$$\bar{n} = \frac{\sum_{1}^{T} n_t}{T}$$

It is possible to state the mean in terms of identification times of the targets. Let t_i be the identification period of target i. Then

$$\bar{n} = \frac{\sum_{1}^{T} T - t_i}{N} = T - \frac{\sum_{i}^{N} t_i}{N}$$

is equivalent of the previously stated objective. Hence minimization of the accumulated time to identification over all the N targets would be an equivalent objective.

3. MODELLING

Multiple targets are assumed each moving on some known straight course at some known constant speed. Hence the locations of targets can be defined at any step.

Let X_{it} (I = 1,2,3,......,N; t=1,2,3,.....,T) denote the location vector of the target i at step t. Since identification of a target does not require to be at its exact location, but within a circle with radius IDRNG drawn around it; let us define C_{it} as the circle with its center at X_{it} and with radius IDRNG.

The origin of two dimensional cartesian coordinate system is taken as the initial location of the observer. Let K_t (t= 0,1,2,....,T) denote the location vector of the observer at step t. The observer is assumed to fly at constant ground speed **|V|**. Therefore the locus of locations that the observer can be at by the end of (t-d)steps starting from any arbitrary location K_d , is the circle with radius (t-d) |V| drawn with the center K_d. Let such circles be denoted by L_t. Starting from K_d, the extreme courses leading to the identification of an arbitrary target i at step t are given by the straight lines joining K_d and the intersection points (if any) of circles C_{it} and L_t . Lines K_dA and K_dB are such extreme courses in Figure 8.

Extreme courses define a zone inscribed in C_{it} over which target i can be identified at step t. Let set of points in this zone be called the set of *available identification points.* There may be infinetely many points in such a set. However it is possible to approximate these points by a finite set to be denoted by P_{it}, called set of *suitable identification points.*

Set of suitable identification points is based on all the remaining targets to be identified subsequent to identifying target i at step t. Since the observer is bound to advance towards one of the remaining targets after step t, it is possible to locate advantageous points among the available identification points. Due to known courses and speeds, it is feasible to look ahead and find advantageous points even when the observer is at K_d .

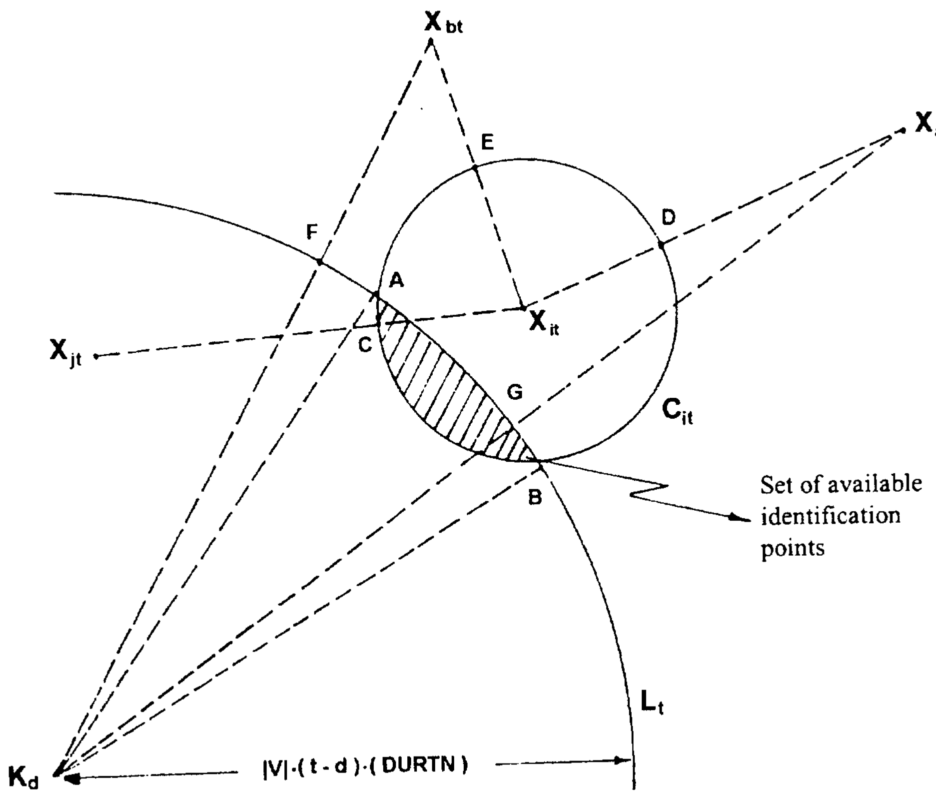


Figure 8. Defining Suitable Identification Points

After the choice of the next target i to be identified when the observer is at K_d , the set P_{it} is determined based on the prospective unidentified targets at t by the following rules:

Let W_t denote the set of targets remaining unidentified at t , with i being the next target to identify at step t when the observer is at K_d .

Rule-1: Determine the intersection points of C_{it} with the lines joining X_{it} and X_{rt} for all $r \in W_t$. In Figure 8, these points are C,D and E for targets j, a and b respectively. Include such points in P_{it} (set of suitable identification points) if they lie over the segment of C_{it} defining the available identification points. Point C in Figure 8 satisifies this rule and hence is included in P_{it}. Exclude from W_t those targets with associated points included in P_{it}. If W_t is empty then no other rule applies.

Rule-2: Determine the intersection points of the circle L_t with the lines joining K_d to X_{rt} for all $r \in W_t$EMBED These points are the G and F in Figure 8 for targets a and b respectively. Include such points in P_{it} if they lie over the segment of C_{it} defining the available identification points. Point G in Figure 8 satisifies this rule an is entered into P_{it}. Exclude from W_t those targets with associated points included in P_{it}. If W_t is empty then the third rule does not apply.

Rule-3: If W_t is not empty after applying the two rules above, include in P_{it} the intersection points of circles L_t and C_{it} lying closest to the positions X_{rt} for all $r \in W_t$EMBED. In Figure 8, point A is closest point to the target b which is included in W_t and hence it will enter into P_{it}

It can be seen that suitable identification points are being selected at a prior time to t, and the main idea behind the selection is to be at the closest location to a subsequent target right after target i is identified at step t. By the three rules above, P_{it}={ C,G,A} in a simple case depicted in Figure 8. In cases where L_t and C_{it} are tangent to each other, P_{it} will contain a single element. In cases where L_t contains C_{it} in its entirity, Rule-1 defines all points in P_{it}.

4. SOLUTION PROCEDURE

A branch and bound like search procedure is applied. The set of suitable identification points, P_{it}, defines the nodes of a search tree, in the form of (i, t, p). A node (i, t, p) represents the alternative of identifying single target **i** at point **p** in step **t**.

The root of the search tree is the node (0, 0 ,0) representing the observer at the origin at step 0. The set of all targets is S = { 1, 2, ..., i, j, ..., N } and the set of unidentified targets at step t is W_t. Hence W_0 = S. The first level nodes branching from the root can be defined as follows:

Step-1: For every $i \in W_0$, determine the minumum number of required time steps to identification, k_i^*, as described before.

Step-2: Determine the set P_{it} for every target $i \in W_0$EMBED for all t ≥ k_i^*. These sets define the first level of the nodes of the form (i,t,p) and represent the alternatives for identification point and time of the first target to be identified.

In the solution procedure, while searching the tree, branching is performed following the embedded priority scheme described below:

Priority Rule: Select the node (i, t, p) not yet branched to with the lowest t. If there more than one node with the lowest t, then select one of them arbitrarly.

Now, the main algorithm can now be stated as follows :

Let n donete the present level of the search tree, $0 \leq n \leq N$. Let Y(i,t,p) = 1 if the node (i,t,p) is to be branched next; else Y(i,t,p) = 0 . Let z denote parent node of the current node. Furthermore, let the array Z(k), k=1,2,3,....N be the stack of ancestor nodes of the current node with the most recent ancestor stored at Z(n). Hence Z(n)=z and Z(1) = (0,0,0). Let Q, Q^* and UB denote the current value, the incumbent value and the upper bound on the objective respectively.

Step 1: Set Q =Q^* = UB = 0; z=(0,0,0) ; $W_0 = S$; and n =1.
Push the root node into the stack Z(1) = (0,0,0) .

Step 2: Define the first level nodes as described above.

Step 3: If no node is left to branch to with z as the parent node then :

3.1: Pop z from the stack, set n=n-1
If n=0 then terminate
If n=1 then set $W_0 = S$
If n>1 then uptade $W_d = W_t + \{k\}$ where k is the target represented in node z ; d is the identification time of Z(n); and t is the identification time of z. Then set z = Z(n)

else

3.2: Branch to (i,t,p) using the embedded priority scheme.
Set Y(i,t,p) = 1,
Q = Q + (T-t) ,
$K_t = p$,
Update $W_t = W_d - \{ i \}$
If $Q > Q^*$ then $Q^* = Q$

Step 4: If $W_t = \{\}$ then

4.1: Y(i,t,p) = 0 and delete the node (i,t,p) out of the tree.
Update $W_d = W_t + \{ i \}$ where d is the identification time of the parent node.
Go to step 3.

else

4.2: If $UB = Q + |W_t| (T - t + 1) \leq Q^*$ then Go to Step 4.1

else

Define the next level nodes branching from the node (i,t,p)
Set n = n+1,
Push the node to the stack Z, Z(n) = (i,t,p)
Set z = Z(n)
Go to Step 3

The test 4.2 means that even the best possible identification time afterwards (at t+1) cannot yield a superior objective than a known solution.

5. SAMPLE SOLUTION AND COMPARISONS

A small scale (3-target) problem is introduced in this section. Three possible flight patterns presented:

(a) an arbitrary flight pattern to identify all targets,
(b) flight pattern to identify all targets proposed by a heuristic,
(c) flight pattern that maximizes the performance criterion described above using the procedure presented in the previous section.

The heuristic will be introduced first, followed by the data for a sample problem and a comparison of flight patterns.

5.1 A Myopic Pattern Construction Approach

Every time it identifies a target, we let the observer choose the next target as yhe one that takes the shortest possible time to intercept among the remaining targets. The identification point for a target is selected arbitrarily. A four step procedure to execute the heurustic approach is described below.:

Step 1: Initialize t = 0, $W_0 = S$, $K_0 = (0,0)$, where t, W_t, S and K_t are the time, the set of remaining targets at time t, the set of all targets and the location coordinates of the observer at time t, respectively. Let (0,0) stend for the origin of the coordinate system where the observer is located initially.

Step2: Determine the ninimum number of time periods k_i^* required to identify target i for all $i \in W_t$. The approach taken is introduced above in the subsection "**Identification in Minimum Time**" .

Step3: Choose a particular target j for which $k_j^* = Min\{k_1^*, k_2^*, \ldots\ldots\ldots, k_{w_i}^*\}$. If there are more than one point to identify target j, k_j^* periods later, select an arbitrary point among the canditates.

Step4 : Advance t to the time of identification for target j, say d.
Update K_d to the coordinates of the selected point.
Update W_d by $W_d = W_t - \{j\}$
If $W_d = \{\}$ then terminate; else go to step 2.

5.2 Sample Problem Data

Table-1 presents data for the initial locations and constant courses for a sample problem of three targets. The coordinates of the initial locations with respect to the observer are supplied in geographical system as used in naval operations and in cartesian coordinate system. The bearing and the course for every target are measured in degrees. The unit for the ranges is nautical miles and speeds are measured in knots.

Table-1 Data For a Sample Problem

Target No	Speed	Course	Geographical		Cartesian	
			Bearing	Range	X	Y
1	20	10	185	40	-3.48	-39.85
2	40	10	15	40	11.64	43.46
3	40	100	358	53	-1.85	52.96

Other relevant data for the sample problem are as follows:
IDRNG = 3 miles (identification range)
|V| = 180 knots (speed of the observer)
DURTN = 50 sec. (duration of discrete time steps)

The following tables indicates the results of the problem solved by three different flight patterns.

Table-2 Identification Sequence and Results with an Arbitrary Pattern

Identification Sequence	Identification Step	Identification Time	Identification Coordinates	
			X	Y
1	14	11' 26"	-2.53	-33.10
2	58	47' 22"	18.37	71.88
3	70	57' 10"	35.75	46.33

Table-3 Identification Sequence and Results with Myopic Pattern Construction

Identification Sequence	Identification Step	Identification Time	Identification Coordinates	
			X	Y
1	14	11' 26"	-2.59	-33.09
3	48	39' 12"	22.79	45.61
2	59	48' 11"	17.78	72.21

Table-4 Identification Sequence and Results with the Proposed Procedure

Identification Sequence	Identification Step	Identification Time	Identification Coordinates	
			X	Y
3	21	17' 09"	12.28	50.06
2	22	17' 58"	13.19	52.33
1	54	44' 06"	-0.40	-22.92

The three flight patterns are compared in terms of :

(1) mean percantage of full information achieved, defined as $\frac{\bar{n}}{N} x\, 100\ \%$

(2) mean time until identification, defined as $\bar{t} = \frac{\sum_{1}^{N} t_i}{N}$

(3) proportion of time used identifying all targets, defined as $\frac{Max\{\, t_i \quad i=1,2,..,N\,\}}{T}$

Table-5 compares the performances of three approaches taken.

Table-5 Comparison of Performances

Flight Pattern	Comparison in Terms of Performance Criterion		
	(1)	(2)	(3)
Arbitrary	35.1	47.4	0.909
Myopic	44.7	41.3	0.766
Proposed	55.7	32.3	0.701

Figure 9 depicts the flight patterns resulting from the three approaches. The first target identification (i.e. Target 3) happens later in the proposed approach than in the myopic approach, deliberately, to have some other target (i.e. Target 2) in the vicinity for a more recent identification of the latter.

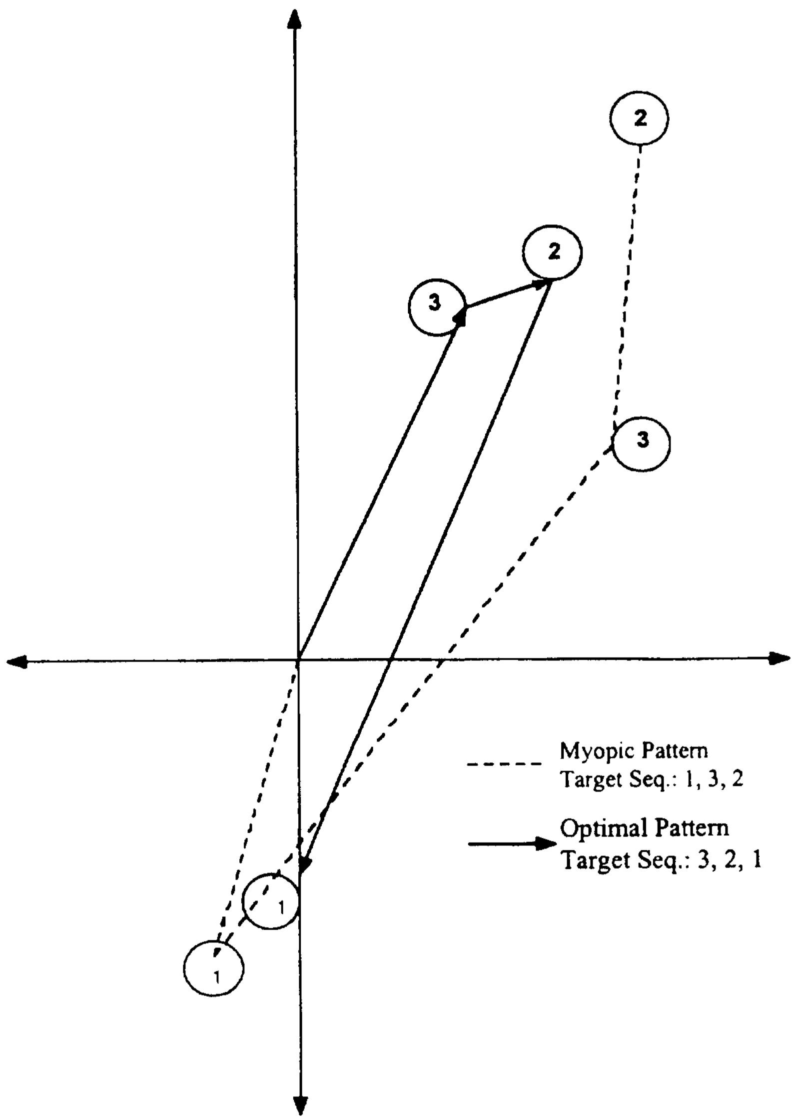


Figure-9. Flight Paths Resulting from (a) Heuristic(Myopic) and (b) Optimizing Approaches

6. DISCUSSION

Computational experiments are performed with randomly generated problems of different numbers of targets. Ten problems are solved for each class of problems vith varying initial locations, speeds and courses of targets. Computational times for the optimizing approach on a PC with Pentium-75 based processor are reported in Table-6

Tablo-5 Computational Time Statistics with Optimizing Approach

Number of Targets	Average	Standard Deviation
3	26 sec.	6 sec.
4	122 sec.	17 sec.
5	876 sec.	98 sec.

The rapid growth in computation time and its variability indicates limitations of the the proposed optimization algorithm. Especially in "one-observer-on many targets" situations, unless more powerful computing facilities are utilized, mission planning in restricted time will become seriously hampered.

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CODE OF BEST PRACTICE FOR THE ASSESSMENT OF COMMAND AND CONTROL

SAS Panel Meeting
Brussels, Belgium
17-19 November 1998

Mr. Robert Bennett, RSG-SAS-002/015 Chairman
US Army TRAC, ATRC-WBC
White Sands Missile Range
New Mexico, 88002-5502, USA

Code of Best Practice for the Assessment of C2

- Represents over 3 years of team effort.
- Evolved from a series of workshops.
- Summarizes current state-of-the-art for conducting evaluation and modeling of command and control.
- Is intended for experienced OR analysts with no prior experience in C2 analysis.
- Is intended for broad dissemination.

Agenda

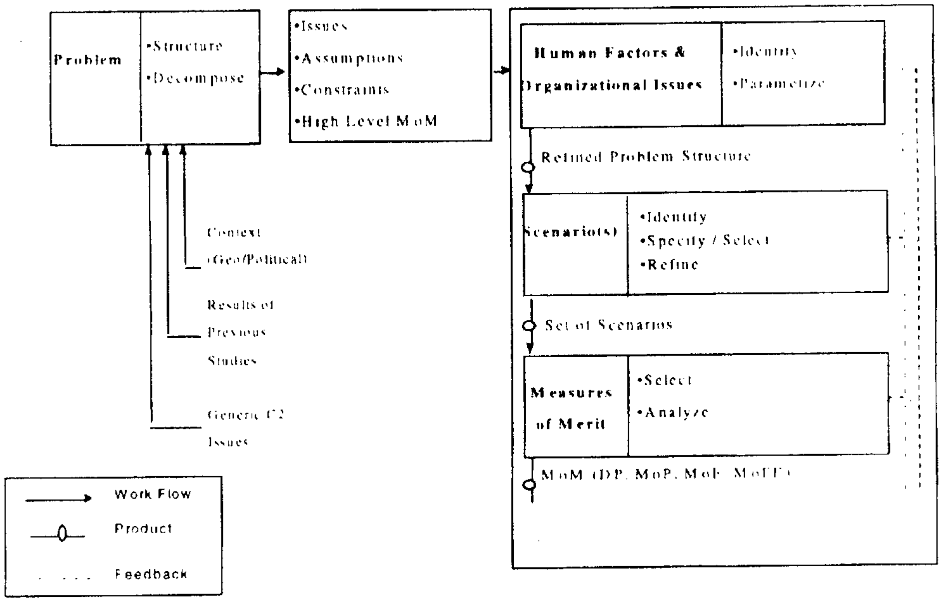
SAS-002 COBP

Conclusions

- Meaningful C2 analyses, while complex and challenging, are possible.
- Traditional OA tools and approaches, while essential, need to be enhanced for C2 analysis.
- Interdisciplinary teams needed.
- No single measure exists.
- Need creative approaches to VV&A.
  - Most effective approach is application of multiple tools and models to cross check results.
- Commonality of approaches exists among nations.
- Existing tools are inadequate. Much work remains for modeling operations other than high-intensity conflict, representation of cognitive processes, and hostile forces.

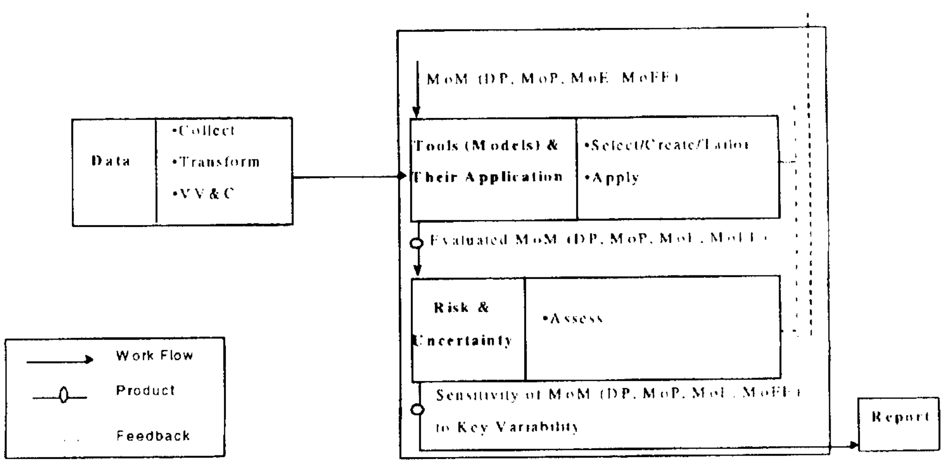
SAS-002 COBP

Recommended Assessment Methodology (1)

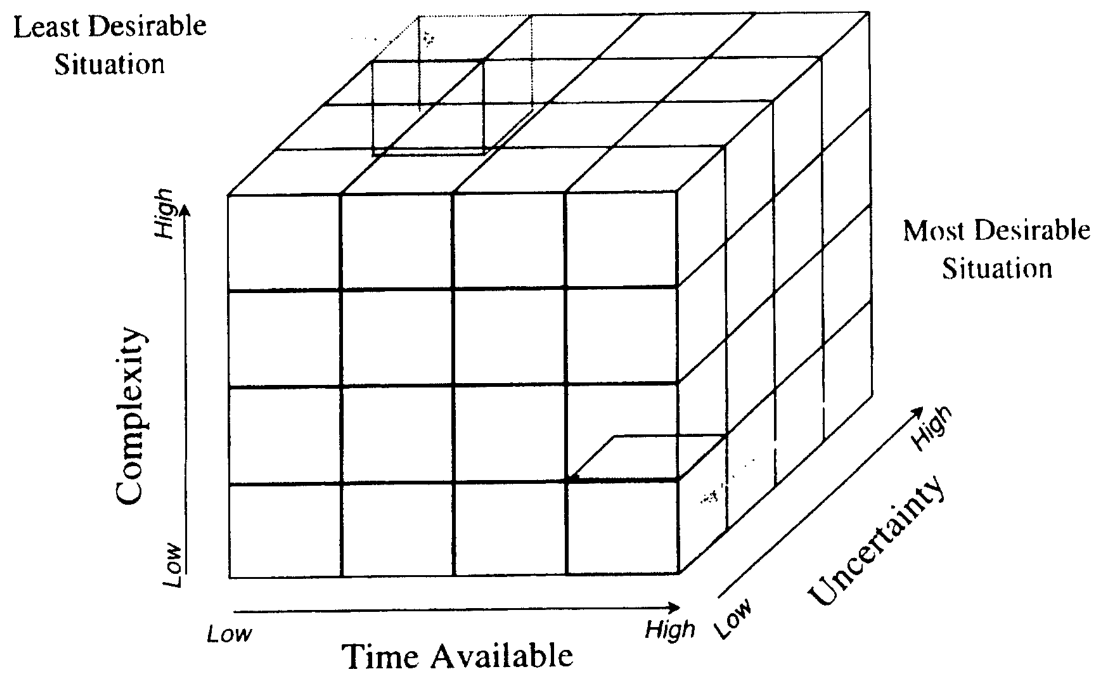


SAS-002 COBP

Recommended Assessment Methodology (2)



Relationships Among Decision Making Drivers



Human Factors and Organizational Issues

- C2 involves distributed teams of humans operating under stress .
- Purpose: determine if it is safe to ignore the human element. Is the performance of the human organization central to the problem?
- Input : organizational structure, tactics, issue, assumptions, constraints, high-level measures of merit.
- Products : refined problem structure.
- Recommended approach: subject matter experts.

Human Factors Issues

- Performance
  - Differences resulting from experience, training, fatigue, doctrine and practice
  - May need experiments to determine performance parameters
- Decision Making
  - Large variety of behaviors involved
  - Decisions range from simple (automatable) to complex
- Quality of Decision Maker
  - If decision making performance will make a difference, must make assumptions or allow for differences within the analysis.
- Command Style
  - Very complex modeling problem - should be explicitly included if necessary to answer analytic questions of interest

Organizational Issues

- Organizational Differences
  - Structure
    - Echelons
    - Span of Control
    - Links
  - Function
    - Distribution of responsibility and authority
    - Distribution of information
    - Functional or integrated organization
  - Capacity
    - Personnel (quality, training, experience)
    - Communications and information systems and architectures

Scenarios

- C2 analysis can only be accomplished in a scenario setting.
- Input : refined problem structure.
- Products : set of scenarios.
- Recommended approach : use multiple scenarios.

Scenario Considerations

- Role of Scenarios
  - Provide Context
  - Accommodate Command Echelons
- Not Generic; Customized to Problem
- C2 Issues to be Addressed
  - C2 Organization
  - C2 Process
  - C2 Systems
  - Human Factors

The Scenario Framework

External Factors

Political/Military/Cultural Situation	Mission Objectives Mission Constraints & Limitations Rules of Engagement	Mission Military Scope Intensity Joint/Combined } Tasks
National Security Interests		

Capabilities of Actors

- Organisation, ORBAT, C2, Doctrine, Resources
- Weapons, Equipment
- Logistics, Skills, Morale,...

Friendly Forces	Adversary Forces	Non-Combatants

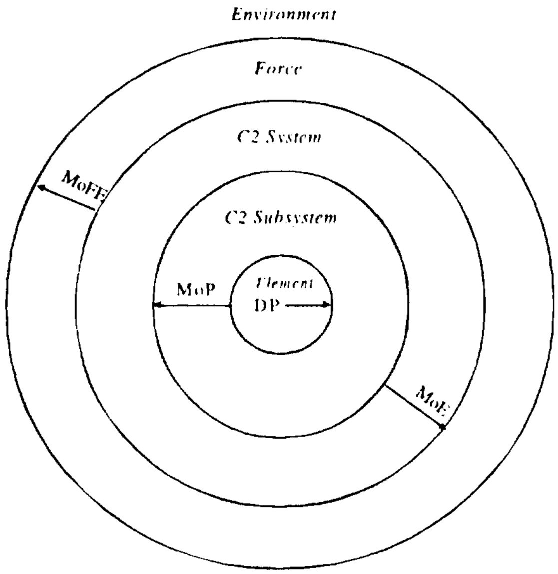
Environment

- Geography/Region/Terrain Features/Accessibility/Vegetation
- Climate/Weather
- (Civil) Infrastructure (e.g., Transportation, Telecommunications, Energy)
- Culture, Economy, International Affiliations

Measures of Merit

- Purpose : provide a means of quantifying the alternatives.
- Input : scenarios, human and organizational factors, problem structure and components.
- Products : DP, MoP, MoE, MoFE.
- Recommended approach :
    - no single measure
    - use multilevel hierarchy linking lower-level MoM to higher-level MoM (Force Effectiveness)
    - determine causality

Relationships Among Classes of Measures of Merit



Legend

DP: Dimensional Parameters

MoP: Measures of C^2 System Performance

MoE: Measures of C^2 System Effectiveness

MoFE: Measures of Force Effectiveness

Categories of Measures of Merit

- C2 System/Hardware Performance Measures
  - Reliability/Maintainability/Availability
  - Commo throughput
  - Positional accuracy
- C2 Measures
  - Focus on C2 Cycle - Monitor, Understand, Plan, Decide, Direct
  - Typically Measure Time and Accuracy
- Force Effectiveness
  - Mission accomplishment
  - Loss exchange ratio

Characteristics of Measures of Merit

- Validity
  - Internal
  - Construct (Content)
  - Statistical (sensitivity)
  - External
- Reliability
  - Repeatability
  - Precision

SAS-002 COBP

Modeling Issues

- Represent C2 causality (C2 MoE→ MoFE)
- Represent Human Behavior
  - Rule-based
  - Algorithmic
  - Man-in-the-Loop
- Homogenous v. Hierarchies/Federations
- Stochastic v. Deterministic
- Adversarial Representation
- VV&A (VV&C where appropriate)

Spectrum of Assessment Techniques

Technique	Typical Application	Systems	People	Ops/ Mission	Resources	Lead Time		Credibility
						Create	Use	
Analysis	Closed Form; Statistical	Analytical	Assumed or Simulated	Simulated	Relatively Modest	Weeks to Months	Weeks to Months	Fair to Moderate
Constructive	Force on Force Models, Communication Systems	Simulated	Assumed or Simulated	Simulated	Moderate	Months to Years	Weeks to Months	Moderate
Virtual	Human in the Loop	Simulated	Real	Simulated	High	Years	Months	Moderate to High
Live	CPX* FTX*	Real	Real	Real or Simulated	Very High	Years	Weeks to Months	High
Actual Ops	After Action Reports; Lessons Learned	Real	Real	Real	Extremely High	N/A	N/A	Very High

*CPX - Command Post Exercise
*FTX - Field Training Exercise

Modelling Guidelines

- Represent Information As a Commodity, including:
  - Flow around battlefield
  - Collection from multiple sources
  - Tasking of multiple collectors
  - Information Processing
- Represent C2 Systems As Battlefield Entities, particularly:
  - Unit perceptions
  - Commander's decisions
  - Execution
- Represent IO for All Combatants, including:
  - Attack on information and information systems
  - Protection of information and information systems

New Modelling Methods

- Model Federations For Example, Object Oriented Approaches
- Agent Oriented Modelling
- Linking Performance Models to Effectiveness Models
- Scan Scenario Space
- Represent Decision Making Process
- Parameter Development

Selected Recommendations from the COBP (1)

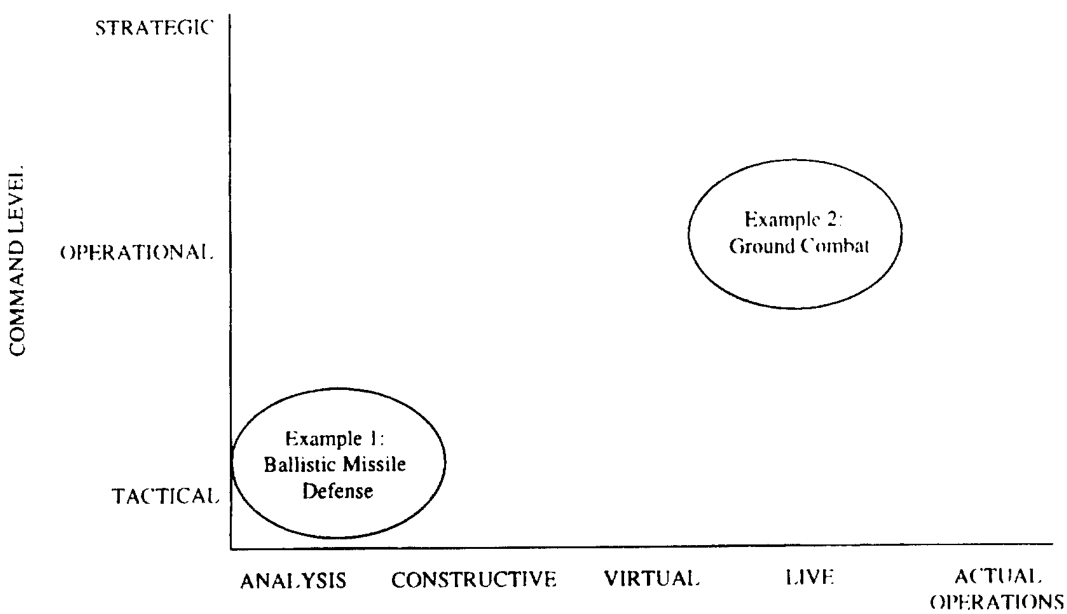
- *Multidisciplinary teams* are generally required.
- Care should be taken in *structuring, decomposing* the problem
  - To enable analyses of the component parts.
  - To facilitate the synthesis of the individual analyses.
- *Multiple scenarios* need to be considered.
- No single *measure of merit (MoM)* exists that satisfactorily allows the assessment of C2 performance effectiveness. A hierarchy of measures should be used.

SAS-002 COBP

Selected Recommendations from the COBP (2)

- A *mix of tools* is generally required to
  - Compensate for the shortfalls of individual tools.
- The need for, and results of, *sensitivity analyses* should be stressed in discussions with decision makers.
- An *iterative approach* should be pursued.
  - Initial cut: broad, shallow
  - Subsequent cuts: narrower, deeper

Practical Examples - Envelope of Possible Studies



SAS-002 SYMPOSIUM ON MODELING AND ANALYSIS OF COMMAND AND CONTROL

SYMPOSIUM CLOSING

Mr. Robert Bennett

SAS-002 SYMPOSIUM ON MODELING AND ANALYSIS OF COMMAND AND CONTROL

- The Symposium director wishes to thank
  - the host nation, in particular, General Marescaux, DGA/DSP, Mr. Jean Reix, and Mr. Marc Galdeano for hosting the Symposium.
  - the presenters and participants for attending the Symposium and making it a success.

THE FIVE AGES OF C3 MODELLING: A PRESENTATION TO THE NATO SAS-002 WG

P L Grainger, UK MoD, Room 2360
MoD Main Building
Whitehall, London SW1A 2HB, UK

1. [Slide 1] I propose to describe several "ages" of C3 modelling.

THE GOLDEN AGE (1938-45)

2. [Slide 2] The 1st, or ***GOLDEN AGE***, lasted from about 1938 to 1945, and is a bit of a cheat, since there were hardly any computers then, and no computer models. However, it is well worth including here since it still has a lot to tell us. It also represents a sort of gold standard against which to judge how far we have progressed since (mostly backwards until recently, at least in my opinion). I particularly have in mind the control and reporting system based on CHAIN-HOME radar information built for UK Fighter Command just before WWII, which was a real system, not a model. Slide 3 shows a picture of a CHAIN-HOME radar station. I will not dwell on the interesting technical aspects here, except to say that such a non-rotating, low frequency radar did not *look* how a radar was supposed to look at the time, which acted as an unexpected deception bonus. The next two slides relate the WWII radar system components to modern C3 modelling terminology, and you should recognise in Slide 5 the standard structure which Jim Moffat has developed in his work.

3. The overall system had several features which we as model designers would do well to remember [Slide 6]:

a. It represented an extremely close collaboration between the scientists and the military, who had a great deal of respect for one another.

b. It was developed in an evolutionary way, and remarkably quickly (1st, *very crude*, UK demonstration of radar February 1935: fully operational radar system Good Friday 1939 - the full system of 20 stations reputedly cost about £10M).

c. It had real data to demonstrate whether it worked or not.

d. It needed to be, and was, remarkably good at data aggregation, since the radars available to Fighter Command were not able to form individual aircraft tracks (in fact, a good case could be made that the ability to form individual radar tracks set the C2 community back about 30 years). Of course the trickier planning and data fusion functions, as well as various technical functions which today are easy to automate, were carried out by human beings in the loop.

e. Without wishing to minimise the purely technical radar advances, the real conceptual breakthrough was specifically about information processing (only quite recently realised as an enabling function in its own right), and making the best use of both the technical and the human components of the system.

f. One important aspect of the system design which still matters today was the clear separation between picture compilation (then performed by what was called the "filter room") and planning/operations. The point is not so much that the specialist nature of picture compilation sets it apart, though there is some truth in this, but that the picture compilation process needs to maintain as much objectivity as possible, and it can best do this by

remaining independent of the rest of the organisation. This minimises built-in biases from commanders who only look for what they expect, or try to ignore bad news. Of course there is a limit to such objectivity, since surveillance assets are a scarce resource which will need to be deployed in a non-random way, and an HQ swamped with data will tend to select data for analysis in a non-random way.

THE DARK AGES (1945-75)

4. [Slide 7] The 2nd period I shall call the ***DARK AGES***, which lasted from about 1945 to 1975. During this period computer models appeared in profusion, the majority of them deterministic models based on the use of Lanchester equations to represent what in reality would be much more complex tactical interactions. The Dark Ages saw an unhealthy separation, still with us, between the "C3 specialists", who concentrated typically on radar and communications in rather narrowly defined problem domains which they felt able to tackle, and the OR modellers, who had the wider perspective to address issues at the operational or strategic level, but lacked effective ways of doing so. C3 was simply ignored, or implicitly assumed to work perfectly, and as a result the models usually generated grossly optimistic effectiveness estimates and far too high attrition rates.

5. An important but mistaken idea which pervaded this period was that any factor like C3, yet to be included in models, represents some sort of second-order effect, and that a model without it could still be relied upon as a "1st-order approximation". The idea that such missing factor biases could be corrected either by statistics (based on historical analysis, for example) or by military judgement was totally anathema to the hard analysts concerned. Only the ability to avoid contact with real data enabled the modellers to remain employed. This period was a damning indictment of OR, and even now we have not fully escaped its legacy.

THE RENAISSANCE (1975-90)

6. [Slide 8] The 3rd period, which lasted from about 1975 to 1990, I shall call the ***RENAISSANCE***. In this period it was increasingly realised just how much C3 mattered, particularly how essential solving the C3 modelling problem was for justifying new C3 hardware to the bean-counters. Faltering attempts were made to represent C3 aspects in models, but often as add-ons to existing model architectures, and often using "quick fixes" like expert systems, which didn't really work. UK models like GenKnoFlexE and IMAGE, and analogous models run by other nations, had rule-bases comprising tens of thousands of rules which were so complex that the models became impossible to understand, a problem compounded by the inconvenient tendency towards chaotic behaviour in deterministic models.

7. Perhaps the most important achievement of this period was the realisation that solving the C3 modelling problem was going to be *very hard*. For example, fundamental problems like the need *not to use ground truth* in establishing the identification of units were appreciated, but there was no way to tackle them, and some absolutely essential C3 functions, like planning, were still largely ignored, except as consumers of time.

8. A parallel development, not specific to C3 but highly relevant to it, was the increasing demand for validated models and audit trails for all data and assumptions used in OR studies. This exposed the considerable weaknesses under which all C3-related studies (ie *most studies*, since it is hard to identify any types of operation *not* affected by C3) were labouring.

THE ENLIGHTENMENT (1990-2001)

9. [Slide 9] The 4th period, lasting from about 1990 to 2001, I shall call the ***ENLIGHTENMENT***. By now we have analysed the problem quite well, and have invested in the fundamental re-thinking required to stand some chance of getting a solution. It is surprising it has taken so long, since the result is simply a common-sense description of how information flows around the C3 system and what happens to it on the way. We have learned that C3 aspects must drive the structure of any OR model, which explains why previous attempts to graft it on to existing models largely failed. We have also homed in on the principal technical problems: data fusion and planning. Though we are making visible and very encouraging progress, these problems have not yet been solved, and it may be optimistic to expect enlightenment to be achieved by 2001.

10. We now have fairly formal procedures for the validation of OR models which are in-place and working, at least in the UK and US. It would be grossly optimistic to claim that all OR models are now therefore valid, since rigorous validation must remain an unachievable goal, but lesser levels of validation are being achieved for the first time, and we are homing in on C3-related issues which will need more validation effort.

11. Slide 10, derived from Jim Moffat's work, shows our current view of the structure of a generic HQ or command agent. It bears an uncanny resemblance to the WWII system in Slide 5, and this is not purely due to the coincidence of having constructed one slide from the other.

THE AGE OF REALISM (2001-?)

12. [Slide 11] At the start of the 5th period, in 2001, we will hopefully have achieved the following:

a. Confidence that OR model results fairly reflect the influence of C3 aspects.

b. The ability for the first time to carry out cost-effectiveness trade-offs between C3 systems (including ISTAR and communications systems), platforms and weapons.

c. The ability for the first time to explore tricky issues which have so far been completely beyond our grasp, such as alternative command styles and rules of engagement.

d. And as a bonus, we should have considerably speeded up the scenario development process, simply by applying force deployment logic such as genetic algorithms to the start of conflict.

13. [Slide 12] It would be nice to have called the speculative 5th period the second golden age. However, I have instead chosen the more downbeat title "the age of ***REALISM***", since I foresee several new problems lying in wait for us:

a. Battlefield digitisation will advance so rapidly that OR models will have considerable difficulty keeping up.

b. If we are not careful there will be a serious confrontation between OR models and synthetic environment software.

c. The better our C3 representations, the more difficult it will be to avoid focusing on the propensity of military commanders to make mistakes. This is what the "fog of war" is really about. How many of you know of even one OR model in which units can actually get lost, for example? Or has GPS totally eliminated this problem? We must expect some antagonism from the military on this issue, or at least the claim that "now we know what the problems are we will be able to avoid them in future", which will of course need to be treated with some scepticism.

d. Of course, no model of C3 will ever be deemed entirely satisfactory by the psychologists, who range from those who believe that the problem of representing the human component is just too complex, to those on the soft fringes of OR who believe that human decisions can only be simulated by a man-in-the-loop, in which case predictive (and efficient) simulation is ruled out.

e. If future conflict dissolves into unstructured multiple confrontations between large numbers of autonomous entities, we may find that we have solved the C3 problem only to discover that OR models are not much good for prediction any more.

f. There will be a serious data problem. If the pressure for validation increases, as it probably should, and synthetic environments are not the whole answer, then there will be an increasing need to squeeze the last drop of useful information out of all real operations. This suggests that, in future, real operations should be almost as heavily instrumented as some of the more futuristic ranges in use in the US. It may well turn out that providing valid data for a model will cost considerably more than developing the model in the first place, and will be prohibitive unless it can occur automatically "on the back of" some other activity.

14. [Slide 13] The final slide attempts to draw some general conclusions from this potted history:

a. A theme running through the whole 60 years is that any scientific pursuit stands or falls by the quality of its data, without which hypotheses cannot be tested. OR suffered from a gross lack of data for far too long after WWII, and even now the situation leaves considerable room for improvement.

b. The long lack of success in modelling C3 in OR models - until quite recently - is hard to explain, since with hindsight most of the excuses given in the past were not very convincing, and recent progress has only really required clear thinking and initiative, rather than some sort of magic solution.

c. Change (technical, geopolitical, doctrinal etc) will always be with us. OR models will therefore always have to fight to stay abreast of developments, and this will require continuous high quality investment in model research and development.

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THE FIVE AGES OF C3 MODELLING

SAS Symposium, Paris, 12-14 Jan 1999

Peter Grainger

UK MoD

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THE GOLDEN AGE (1938-45)

- *No* computer models
- However, the UK *CHAIN-HOME* air defence radar system did contain all the relevant C3 components and should have taught us lessons about C3 modelling

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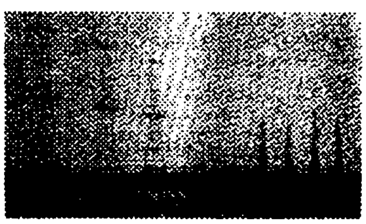
A CHAIN-HOME RADAR STATION



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THE CHAIN-HOME C3 SYSTEM: COMPONENTS

- Sensors = Chain-Home Radars (+human observers+fighters)
- Communications = Land Lines
- Data fusion = "Filter room"
- Recognised Picture = Plotting Table
- Decision = Allocation of Air Defence Fighters to Threat
- Orders to Sectors/Airfields/Anti-Aircraft Batteries

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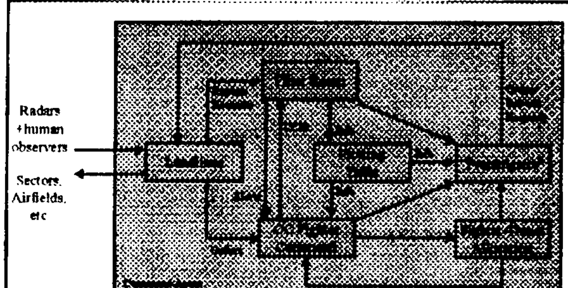
THE CHAIN-HOME C3 SYSTEM: COMMAND-AGENT STRUCTURE



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THE CHAIN-HOME C3 SYSTEM: LESSONS

- Close military-civilian collaboration
- Very rapid evolutionary development
- Real "validation" data
- Very good at data aggregation
- Made best use of available technical and human resources
- Clear separation between picture compilation and planning/operations

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THE DARK AGES (1945-75)

- Many computer OR models
- Unhealthy separation between low-level C3 specialists and OR modellers
- C3 almost totally ignored in OR models, or assumed to work perfectly
- Wrong idea that model without C3 should still be acceptable as a "1st order approximation"
- Far too high attrition rates and optimistic performance estimates
- Peacetime lack of real validation data

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THE RENAISSANCE (1975-90)

- C3 modelling gap, and the pressing need to fill it, fully recognised
- Faltering attempts made to model C3:
  - Add-ons to existing models unsuccessful
  - Expert systems failed to fulfil promise
- Realisation that modelling C3 properly was going to be *hard*
- New and increasing demand for model validation

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THE ENLIGHTENMENT (1990-2001)

- We now have a much clearer analysis of the requirement
- Data-flow representation just common-sense
- C3 aspects must drive model structure
- The outstanding problems are planning and data fusion
- Formalised validation process in US and UK

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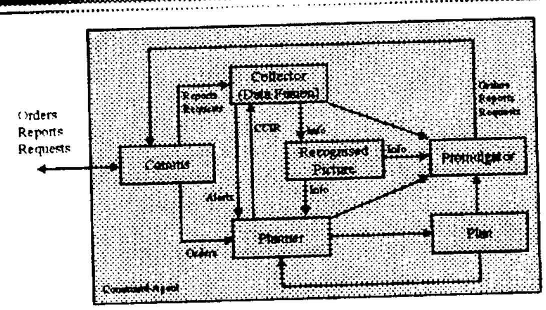
STANDARD HQ/COMMAND-AGENT MODULE



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THE AGE OF REALISM (2001-?)

- We should be able, for the first time, to:
  - Reflect C3 influences properly
  - Carry out cost-effectiveness trade-offs between C3 systems, platforms and weapons
  - Explore hitherto tricky areas, like rules of engagement and command styles
  - Automate scenario setup to a useful extent

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THE AGE OF REALISM: THE DOWN SIDE

- *But* there are new problems lying in wait for us:
  - Battlefield digitisation
  - OR models v synthetic environments
  - Good C3 representation = "Fog of war" = commanders' mistakes
  - The human component
  - Future conflict may be too unstructured for any model to have much predictive value
  - Where will the data come from?

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LESSONS FROM THIS HISTORY

- Any science without a firm data foundation risks being worthless
- Many of the excuses given in the past for avoiding the C3 modelling problem (such as "the man-in-the-loop is too difficult to model") were either spurious or highly exaggerated
- Change (technical; geopolitical; doctrinal etc etc) will always be with us. OR models will always have to fight to keep up, and continuous high quality investment in OR model R&D will be essential

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Representation of Command and Control (C2) and Information Operations (IO) in Military Simulations

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Abstract

The representation of command and control (C2) and command decision processes, through the use of modeling and simulation (M&S) techniques, has become a key element of Department of Defense (DoD) technology initiatives in the areas of analysis and acquisition, operations planning and execution, and training. It has become increasingly apparent that if DoD sponsored military simulations are to effectively represent the entire battlespace, it is imperative that they accurately simulate C2 and related command decision activities as well as the impact that deep sensors, communications, and information flows have on these processes. The closely related issues of accurately representing information operations (IO) and command and control warfare (C2W) are also becoming increasingly prominent within the DoD analysis, operational, and training communities. The purpose of this paper is to discuss recent advances in modeling and simulation practice which specifically address the representation of C2, IO, and C2W processes.

More specifically, this paper describes the command and control (C2), information operations (IO), and C2 warfare (C2W) representations implemented within the Naval Simulation System (NSS).

1.0 Introduction

This paper describes recent advances in modeling and simulation practice which specifically address the representation of command and control (C2), information operations (IO), and C2 warfare (C2W). The following are working definitions of C2, IO, and C2W upon which this discussion is based.

Command and Control (C2) is defined to be the exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission [JCS].

Information Operations (IO) is defined to be any action to exploit, manipulate, or destroy an adversary's information and/or information systems while leveraging and defending friendly information and information systems to achieve information dominance [Sabalos, 1995].

* This work has been performed under NRL Contracts N00014-95-C-2064 and N00014-95-C-2037.

Command and Control Warfare (C2W) is defined to be the military strategy that implements IO on the battlefield [C2W]. Also see Appendix A for an overview description of IO and C2W.

Providing adequately realistic and robust modeling and simulation (M&S) representations of the Military commander's decision process is a very challenging problem domain which at best is only partially addressed in existing Department of Defense (DoD) sponsored models and simulations. Representation of information based warfare, e.g. IO and C2W, is similarly difficult. This paper will focus largely on *constructive*[1] models and simulations used for analysis and acquisition, operational planning and execution, and training. We believe, however, that this work has some degree of applicability to *virtual*[2] and *live*[3] simulation domains as well, although this will not be discussed further in this paper.

Many approaches for simulating human decision-making processes have been attempted. All have associated strengths and weaknesses. In a recent RAND Corporation report [Hillestad *et al.*, 1995], it was noted that many aspects of human decision-making *"are so poorly understood that they cannot currently be represented with any degree of realism. It is only in extremely structured game situations, such as chess, that we have had any success in getting computers to adequately compete with people at a high level."* Our experience to a large extent confirms this view; there are elements of the command decision process which are clearly beyond the current M&S state-of-the-art. We have also found, however, that there are elements of the command decision process which **can** be adequately addressed provided certain M&S practices are observed. From an M&S *simulation* technology standpoint, we believe that there are seven key areas which must be addressed in order to provide sufficiently realistic and robust (M&S) representations of (portions of) the Military commander's decision process. These seven key M&S technology areas are as follows:

Collection: Representation of the collection of all-source surveillance/ intelligence data including information content and information uncertainty. This includes modeling the dependencies on threat type and state, collection system type and state, and environment.

Dissemination: Representation of the means by which all-source surveillance/ intelligence data is communicated to processing, evaluation, command, and execution nodes.

Fusion: Representation of the means by which all-source surveillance/intelligence data is processed into information suited to the Military commander. This includes various forms of derived data extraction, correlation, and state estimation (fusion).

Operator Displays: Representation of the form in which fusion products are provided to the Military commander.

Situation Assessment: Representation of the means by which situation assessments are obtained and provided to the Military commander, e.g. assessment of threat intent.

Decision Process: Representation of the decision process itself, e.g. the procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission.

Metrics: Providing the means to measure the ability of the surveillance/intelligence architecture to collect key tactical data, the ability of the communications architecture to deliver key surveillance/intelligence products, the marginal utility of specific surveillance/intelligence products to decision making, and other related quantities.

Table 1 provides a summary description of the authors' assessment of the current state-of-the-art in each of these seven key M&S technology categories. These assessments are provided in the form of rankings of technical maturity from 1 to 5.

---

[1] *Constructive* simulation involves simulated people operating simulated systems, e.g. combat models, costing models, performance models [DoD M&S].

[2] *Virtual* simulation involves real people operating simulated systems, e.g. SIMNET, BFTT, CCTT [DoD M&S].

[3] *Live* simulation involves real people operating real systems, e.g. conducting training and testing on instrumented ranges [DoD M&S].

M&S Technology Area	Technical Maturity
1. Collection	Mostly <2>, with some <3>,<4>, and <5>
2. Dissemination	<1>
3. Fusion	Mostly <3> with some <2> and <1>
4. Operator Displays	<2>
5. Situation Assessment	Mostly <5> with some <4>
6. Decision Process	<4>
7. Metrics	<1> - <3>

Levels of Technical Maturity:
<1> High, routinely modeled in full generality.
<2> Medium, routinely modeled to some extent.
<3> Medium, some partial treatments.
<4> Low, some partial treatments.
<5> Low, not currently modeled.

Table 1. Key M&S Technology Areas

Level 1 items are the most technically mature and level 5 items the least. See Table 1 for a fuller definition of levels 1-5.

The work reported in this paper is based in large part on the authors' experience in designing, implementing, and using the Naval Simulation System (NSS) and precursor models (see Appendix B). NSS is a next-generation, object-oriented, multiple-warfare simulation system which represents C2 and C2 systems in a fully integrated and comprehensive fashion. NSS specifically addresses each of the key technology areas identified above and in several instances (as is discussed further below) represents an advance in the current state-of-the-art in Military M&S practice.

2.0 Proposed C2 Representation Requirements

Candidate approaches applicable to the key M&S technology areas and shortfalls cited above must be evaluated in light of a well-articulated set of end-user requirements. This section provides a proposed set of user requirements, in the form of a required capabilities checklist or questionnaire, applicable to constructive simulations in the analysis and acquisition, operations planning and execution, and training problem domains. Specifically, we believe that any constructive M&S representations of C2, IO, C2W and related processes should be evaluated in light of the following requirements checklist:

How are command relationships represented?

- By what mechanism are command organizations (at the same or different levels) represented?
- By what mechanism are interactions between commanders represented?
- Are the real world relationships between the C2 organization, C2 doctrine and rules of engagement (ROEs), and simulated force interactions represented in the simulation?

How is the deliberate planning process (i.e. development, execution, and dynamic revision) represented at each of the following levels?

- Theater,
- Force, and
- Unit.

How is the observe-orient-decide-act (OODA) cycle represented?

- How are the simulated commander's imperfect perceptions concerning the disposition, actions, and intentions of friendly, hostile, and neutral forces acquired and fused? At what level are the intelligence, surveillance, and reconnaissance reporting processes modeled?
- How does the operational/tactical environment (i.e. threat condition, ROEs,

emission control - EMCON conditions, etc.) impact the simulated commander's decision-making process?

- How robust is the treatment of decision criteria for simulated commanders responding to perceived events in the battlespace?
- How are command decisions promulgated to subordinate forces for execution and how are these forces allocated between competing tactical commanders?

How does the analyst input tactics or command behavior during set-up of an analysis run so that alternative command behaviors in identifiable combat situations at different command levels can be selected and assigned to appropriate commanders by the analyst?

- This must not require code level familiarity with the simulation system.
- The specific command situations for which command decisions are represented must be identified in the language of a military commander or command staff analyst.
- The alternative command decisions for each identifiable situation must be selectable by the analyst without requiring the analyst to write code and recompile executable code for the simulation system.
- The analyst must be able to prioritize alternative command decisions so that command alternatives are selected during a simulation run with full dependence upon the uncertainties associated with knowledge of the perceived situation in which a command decision is required.

Can metrics be computed by the simulation that directly measures the effectiveness or impact of alternate command behaviors in specific command situations? It must be possible to assess the effect of using alternate command behaviors for any of the opposing sides in the conflict. This is required specifically to measure the dependence of weapon system and command and control process effectiveness upon specified commander behavior.

- Operational plans include ROEs and (other) decision logic. The effectiveness of the plan must be assessed with respect to alternate command behavior.
- A post-analysis capability must be provided which is capable of performing "parameter dependence" studies to assess performance sensitivity to a range of different command behaviors which might be expressible as alternative prioritization's of possible tactical command decisions.

The selection or recommendation of candidate decision-making modeling approaches (such as man-in-the-loop simulation, scripted decision making, rule-based decision table methods, tactical algorithms, value-based methods, learning methods, searching algorithms, or objective-driven optimization and gaming methods) must be evaluated in light of responses to the requirements-based questions posed above.

3.0 NSS Representation of C2, IO, and C2W

The experience of the NSS design and development team suggests that the quantitative representation of C2 and C2 systems via simulation is very involved and at a minimum must address: (1) command structures and relationships; (2) representation of operational plans; (3) simulation of plan execution including dynamic/responsive asset allocations; (4) tactical picture generation; (5) dissemination of surveillance and intelligence products; and (6) simulation of surveillance and intelligence product collection and generation. The NSS design and implementation for addressing each of these very complex C2, IO, and C2W processes and systems is described in detail in the paragraphs that follow.

3.1 Collection of Surveillance/Intelligence Data

NSS supports the explicit representation of surveillance platform kinematics (space, air, surface, subsurface). Surveillance platform search and surveillance tactics (including those for unmanned undersea vehicles - UUVs and unmanned air vehicles - UAVs) may also be explicitly simulated. Surveillance system coverage volume geometries may be modeled at multiple levels of resolution ranging from simple 3-D cookie-cutter to complex 3-D cookie-cutter to propagation physics based. At all levels of resolution, see Table 2, surveillance system

Title	Description
Simple Parametric Sensors (S1)	Under this option, sensors in selected categories are characterized by a small set of parameters (e.g. a detection range; a "glimpse" rate; a list of detectable vulnerabilities; and probabilities of detection, classification, identification, raid count, and battle damage assessment per "glimpse").
Detailed Parametric Sensors (S2)	Under this option, sensors are specialized by type and characterized by an expanded set of parameters including restrictions expressed in terms of altitude; azimuth; elevation; RCS; radial velocity; line-of-sight limits; performance variability by environmental province or due to terrain, etc.
Physics Based Sensors (S3)	Under this option, sensors are modeled at the propagation physics level of detail. This level of modeling requires extensive supporting sensor, target, and environmental data sets and is often very computationally intensive. Physics based sensor modeling has been deferred.

Table 2. Sensor Related Model Resolution Options

volumes may depend upon surveillance system/platform parameters, target parameters, and the environment. A full spectrum of sensor systems and sensor platforms are represented as summarized in the Table 3. Surveillance system reporting **rates**, reporting **information content**, and reporting **uncertainties** can be user specified. Specified information content can include location, lines-of-bearing (LOB), velocity, classification, identification, group count, battle damage assessment (BDA), etc. Reporting uncertainty parameters include probability of detection, mean positional uncertainties, mean velocity report uncertainties, probability of correct classification, etc.

In addition, detectable platform kinematics and behavior (air, land, surface, and subsurface) may be explicitly represented. Detectable platform susceptibility to detection may also be user specified, e.g. susceptibility by sensor type, susceptibility windows (random, deterministic, or event-based), dependency on environmental region, etc. For instance, a mobile missile launcher may be PHOTINT and/or MTI radar detectable while in transit (and hence out from cover), IR detectable while launching missiles, and COMINT detectable while communicating. Detectable platform tactics and doctrine to avoid detection may also be simulated.

3.2 Dissemination of Surveillance/Intelligence Data

NSS supports the explicit simulation of tactical data including contact reports, warning reports, command and control messages, and others. Each simulated platform or facility may have a user-specified communications suite and communications plan. Specific communications systems may be represented at multiple user-selectable levels or resolution (see Table 4). These levels of resolution range from simple non-

Platform	Sensor Types
Space	Radar, ELINT, COMINT, PHOTINT, IR, Other Nonacoustic
Air	Radar, ELINT, COMINT, PHOTINT, IR, Passive Acoustic, Active Acoustic, Other Nonacoustic
Afloat	Radar, ELINT, COMINT, Passive Acoustic, Active Acoustic, Other Nonacoustic
Ashore	Radar, ELINT, COMINT
Deployable	IUSS, FDS, Trip Wires, ADS, Others

Table 3. Littoral Warfare Sensor Requirements

system-specific parametric representations to detailed system-specific parametric representations to system-specific protocol level representations. NSS currently includes protocol-level representations of several tactical data links including Link-11, Link-16, and TRAP/TRE. NSS communications system representations may also account for required line-of-sight, over-the-horizon, or other physical communications connectivity constraints as appropriate. Specific message sets (e.g. TADIL A, TADIL J, etc.) can be simulated including formats, full information contents, and reporting periodicities. Key communications issues which can be addressed include Joint service interoperability, connectivity requirements, system contention, timeliness, and others.

All communications are simulated in accordance with an operational communications plan. This communications plan can specify detailed routing data for each sender and/or originator and message type including route precedence and route segments. Each route segment can include specification of network, network processing delays, intermediate destinations, and final destinations. Realistic message routing, involving arbitrary numbers of networks, relay nodes, and intermediate processing nodes can be explicitly simulated. Statistical background message loading, accounting for messages not explicitly simulated, can also be included.

3.3 Processing of Surveillance/Intelligence Data

Fusion is the correlation and integration of data on enemy forces obtained from multiple sources into a perceived enemy situation. Fusion is one component of the intelligence development process used in the execution of military operations. The representation must permit traceability from raw intelligence data through situation assessment to military action. It should be noted that the representation of assessed intelligence vs. raw surveillance data (e.g. the assessment that a particular threat surface ship is laying mines vs. the simple detection, classification, and identification of the surface ship itself) is an area that NSS is just now beginning to address. Hence this aspect of the intelligence fusion process is less mature in NSS than the representations of surveillance, communications, data fusion, and plan execution.

NSS includes explicit simulation of tactical picture processing. As is illustrated below in Table 5, the simulation of tactical picture processing is supported at four user selectable resolution settings. Tactical picture processing model options include: ground truth fusion, perfect correlation with dead-reckoning fusion, imperfect correlation with dead-reckoning fusion, and imperfect correlation with Kalman Filter fusion. Under ground truth fusion, all tactical pictures contain exactly one track for each friendly, hostile, and neutral platform with perfect location, velocity, classification, identification, etc. data at all times. Under perfect correlation and dead-reckoning fusion, all contact reports are correctly correlated (and all false alarms are

Title	Description
Assured Communications With Stochastic Delay (C1)	Under this option, all selected communications are assured (subject to user specified delay distribution) in accordance with the communications plan.
Unassured Communications With Simple Constraints (C2)	Under this option, C1 logic is employed plus links may have additional simple restrictions (e.g. line-of-sight, frequency compatibility, etc.).
Protocol Level Communications (C3)	Under this option, the protocols associated with specific communications systems are explicitly modeled (e.g. JTIDS slot block assignments and logic, TRAP/TRE access slot assignments and logic, etc.).
Physics Level Communications (C4)	Under this option, propagation physics is explicitly modeled. Requires extensive communications system and environmental data sets and is computationally intensive. Physics based communications system modeling has been deferred.

Table 4. Communications Related Model Resolution Options

rejected) and track position and velocity is estimated using dead-reckoning from the latest contact report. Under imperfect correlation and dead-reckoning fusion, contact correlation is simulated using a geofeasibility based measure of correlation (hence, false alarms are not necessarily rejected). Under imperfect correlation and Kalman Filter fusion, track position and velocity is estimated using a Kalman Filter. Simple Bayesian methods are used to "fuse" non-positional and velocity related track data. NSS currently does not address detailed ELINT correlation and fusion (i.e. it does not fuse simulated ELINT contacts based upon a detailed emitter characteristics database), although this shortcoming will be addressed in the near future.

Each command node in an NSS simulation generally may have an associated air, surface, subsurface, and land tactical picture. At any time during the simulation, each tactical picture is composed of tracks (correlated contact reports plus an estimate of current state), uncorrelated contact reports (contact reports which have yet to be correlated with a track or used to start a new track), and ambiguous contact reports (contacts which ambiguously correlate to multiple tracks). In addition, each simulated tactical picture can be queried by a simulated commander at any time during the simulation, e.g.

- Find all threat subsurface tracks in region R at the current time,
- Find all surface tracks projected to be within range D of location L at time T.
- Etc.

Simulation of scripted as well as dynamic or responsive actions can be predicated upon such queries. For example, a trigger for a particular responsive mine clearing operation can be the assessment that mines have been deployed in a specific mine danger area (MDA). This assessment in turn can be set to be invoked at any time during the simulation that the Mine Warfare commander's tactical picture projects that some minimum number of threat surface units of a specific type project to be operating in the MDA at the same time.

Each simulated tactical picture represents one commander's simulated *perception* of one problem domain, e.g. air, land, ocean surface, or undersea. Simulated tactical picture "quality" depends upon both the received tactical and theater intelligence and surveillance data as well as the tactical picture processing algorithm employed. *All simulated decision-making in NSS is based upon the commander's perception as represented by the relevant simulated tactical picture. Under no circumstances are simulated commanders allowed to make decisions based on ground truth knowledge of threat, neutral, or friendly forces (unless, of course, the analyst elects to use the ground truth data fusion resolution setting).*

Title	Description
Ground Truth Fusion (F1)	Under this option, the selected tactical pictures contain ground truth location, velocity, classification, ID, raid count, and BDA data for all friendly, hostile, and neutral platforms. When selected (e.g. for friendly forces, hostile forces, or all forces), no sensors for the applicable force(s) are simulated.
Perfect Correlation, Dead Reckoning Fusion (F2)	Under this option, all contacts are assumed to be correlated perfectly. Dead reckoning is used to estimate target positions.
Imperfect Correlation, Dead Reckoning Fusion (F3)	Under this option, attribute matching and a simple measure of correlation (MOC) with thresholds approach is used for contact correlation. Dead reckoning is used to estimate target positions.
Imperfect Correlation, Kalman Filter Fusion (F4)	Under this option, F3 correlation is employed along with a Kalman Filter for estimating target positions.

Table 5. Data Fusion Related Model Resolution Options

3.4 Display/Presentation of Surveillance/ Intelligence Data

During actual Military operations, commanders deployed on command platforms or at command facilities are provided various types of surveillance and intelligence data in various formats and display mediums. Both the content

and format of this information is typically of decisive importance. Within a simulated representation of the command decision process information content and format is important as well. Within NSS, each simulated commander is provided with the following simulated tactical information sources: **Tactical Picture:** As described above, each commander is supported by simulated air-, surface-, subsurface-, and ground-based tactical pictures. The resulting track databases can be queried for past, present, or (projected) future track state information. Local and remote all-source surveillance and intelligence data feeds into these simulated tactical pictures in accordance with the user-specified surveillance and communications architectures and plans.

Own-Force Status: Each simulated commander can also query own-force platform or subsystem status through the simulated communications of status update requests.

Well-defined tactical data access for simulated commanders has proven to be a key step toward developing a sufficiently general and robust representation of the military commander.

3.5 Situation Assessment

Another key issue in the representation of the command decision process is the mechanism by which one alliance perceives the battle objectives of another. At one extreme, threat battle objectives could be assumed "known" to simulated decision makers on a global basis within the simulation; at the other extreme perception of threat objectives could be entirely dependent on simulated sensor and situation reports.

In NSS, the battle objectives of the enemy are known to simulated friendly commanders **only** through the outputs of simulated tactical pictures. The same is true of enemy perception of friendly objectives. Recall that simulated tactical picture outputs depend entirely on simulated sensor and situation reports. Enemy objectives or intentions are determined and acted upon through the use of dynamic response decision tables as described elsewhere in this section (see Table 7). Some simple examples of dynamic response triggers are as follows:

- If n or more surface ships classified hostile and identified to be mine layers are observed within region R during time interval I, employ mine countermeasures plan P.
- If n or more aircraft classified hostile and identified as fighter/attack aircraft are observed inbound within range R of defended asset A, deploy CAP grid G with launch and recovery cycle C.

We have found such dynamic trigger and response input mechanisms to be very robust and intuitive to the Military analyst. The basic mechanism can also address time varying indications and warning (I&W) or other trigger data. Nevertheless, we believe that ultimately more advanced treatments of intelligence processes (e.g. assessments of threat objectives and intent based upon more complicated considerations) will be needed.

3.6 Commander's Decision Process

NSS addresses the representation of the Naval command decision process in Littoral Warfare environments. Littoral warfare concerns Joint military actions in the littorals, i.e. in coastal regions ranging from roughly 20 miles inland to the adjacent oceans areas out to 100 miles offshore. Hence the main focus of littoral warfare is creating secure areas ashore, moving troops and assets ashore, withdrawing troops and assets from positions ashore, and land warfare. Complementing this Joint perspective are the more 'traditional' Navy mission areas such as: air warfare - AW; surface warfare - SUW (especially vs. small, fast attack boats); undersea warfare - USW (especially vs. small diesel submarines); and mine warfare and mine countermeasures (MIW/MCM). Littoral Warfare may also include the Navy-Army theater missile defense (TMD) mission area. Underlying these major mission areas are the operational support areas of logistics, communications, and surveillance. As was learned during Desert Storm, the ability or inability to deliver surveillance information generated by overhead, organic air, and nonorganic air (including UAVs) assets to on-scene tactical units in a sufficiently timely manner may be of decisive importance. NSS is designed to permit the analyst to quantify theater-level performance while correctly accounting for the interdependencies between these disparate major and supporting mission areas.

3.6.1 Command Structures and Relationships

NSS allows the analyst to define friendly and hostile "alliances" and to also identify "unallied" countries. Each alliance is composed of some number of specific member countries or "flags;" e.g. friendly alliance – USA, UK, JAP, SK; hostile alliance – NK; unallied countries – CHIN, RUS. NSS also allows the user to define the command structure associated with each friendly or hostile alliance. Friendly or hostile command structures may be defined which encompass National, Theater, Force and Unit levels of command. These command structures are created by the user and may be defined as general hierarchical command structures composed of three generic commander types (see Figure 1): Group commanders, Warfare Mission Area (WMA) commanders, and Asset commanders. Group commanders command groups of assets, e.g. a Carrier Battle Group (CVBG) commander would be represented as a Group commander. Each Group commander may have subordinate Group commanders, WMA commanders, Asset commanders, and assets. A WMA commander is a commander with responsibility for a specific mission area, e.g. strike warfare. Each WMA commander is subordinate to a Group commander and must contend for group assets with other WMA commanders subordinate to the same Group commander. A WMA priority scheme is used to determine which WMA commander gets priority when too few assets are available to support all mission areas. An Asset commander is associated with each simulated asset, i.e. with each simulated platform or facility. The user-specified operational plans and dynamic responses associated with each type of commander are described in the paragraphs that follow.

At the Group commander level of command, the NSS user is able to define subordinate groups, WMA commanders, assets, warfare mission area (WMA) priorities (vs. time), and operational plans. The assigned subordinate assets are those assets (platforms or facilities and systems) under the direct control of the Group commander. Note that a Group commander may also control assets indirectly, through subordinate commanders with assigned assets. Warfare mission area (WMA) priorities are used to determine which operational plans are executed when asset availability constraints preclude the execution of all plans (e.g. routine surface surveillance flights might be canceled in favor of self-defense against a coordinated strike), see Table 6. WMA priorities are entered as a function of time and the specified priorities may be dynamically changed given preset exceptions, e.g. an AW attack may be set to automatically cause the AW priority to be increased to 1 and all other decremented by 1.

(Example) WMA Priority Table								
	Default Conditions (Scenario Hrs)				Exceptions			
WMA	0 to 48	49 to 50	51 to 60	etc	AAW Attack I&W	ASW Attack I&W	Mine I&W	etc
AAW	3	4	2		1	(current +1)	(current +1)	
AMW	8	8	8		(current +1)	(current +1)	(current +1)	
ASuW	2	3	6		(current +1)	(current +1)	(current +1)	
ASW	1	2	7		(current +1)	1	(current +1)	
LW	9	9	9		(current +1)	(current +1)	(current +1)	
MCM	4	5	4		(current +1)	(current +1)	1	
MIW	5	1	5		(current +1)	(current +1)	(current +1)	
STW	7	7	3		(current +1)	(current +1)	(current +1)	
TMD	6	6	1		(current +1)	(current +1)	(current +1)	

Table 6. WMA Priorities Selection Interface

As is illustrated below in Figure 2, all NSS force assets (i.e. all platforms and facilities) are supported by (or "contain") numerous subsystem managers and one or more commanders. Each force asset may thus "contain" one or several subsystem managers plus one or several commanders. Subsystem managers provide an interface between the force asset (i.e. the platform or facility) and its associated subsystems (e.g. communications systems, sensors, weapons, logistics systems, etc.). As was discussed above, associated commanders may be of three different types: Group commander, Warfare Mission Area (WMA) commander, or Asset commander. The Asset commander (one per asset) interfaces with and controls all subsystem managers associated with the asset. A Group commander, which may be embarked on a specific asset, controls a collection of assets. A WMA commander, which may also be embarked on a specific asset, periodically requests control of collections of assets from the cognizant Group area commander in order to perform a specific mission (e.g. strike warfare). Assignment of the requested assets is based upon the priority of the requesting WMA commander and the availability of combat capable assets of the type requested. All commanders are supported by user-defined tactics and plans and

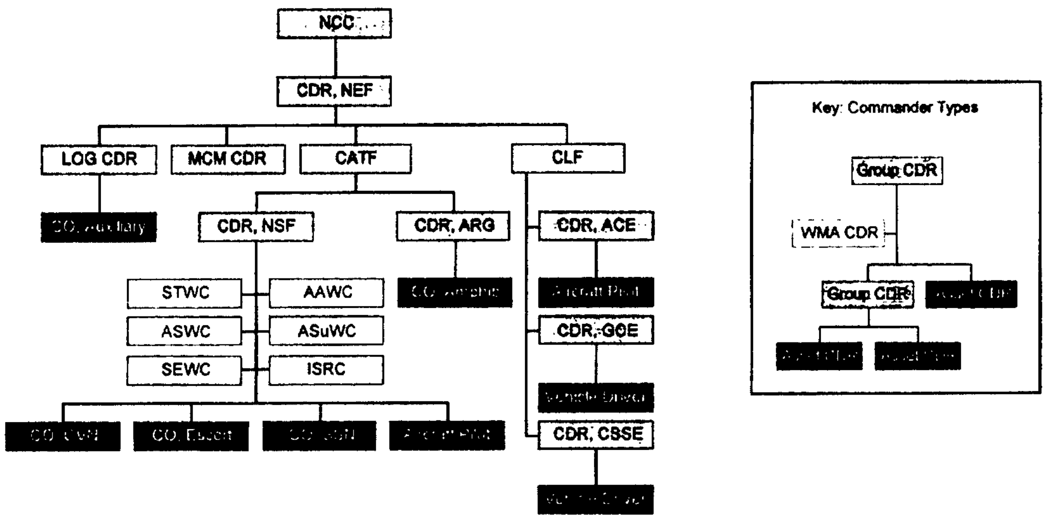

Figure 1. Example NSS Command Structure

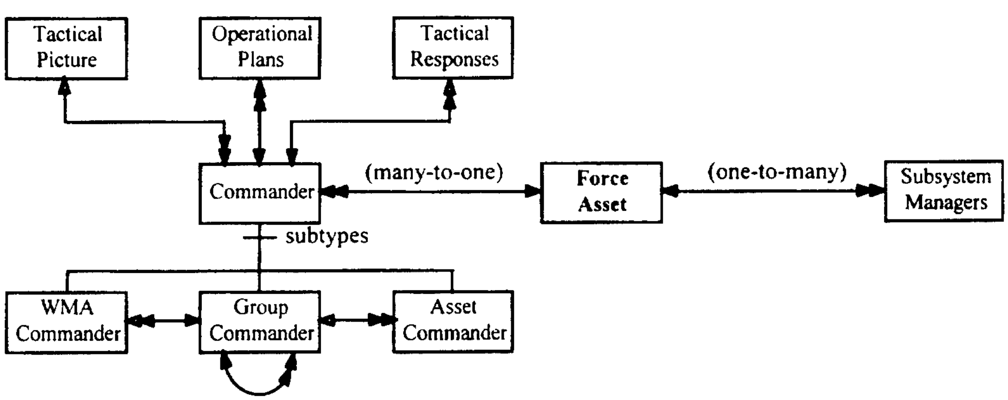

Figure 2. Force Asset Embarked Commanders and Managers

simulated tactical pictures. A description of the NSS treatment of tactics, operational plans, and tactical picture generation is provided in the next section.

3.6.2 Representation of Operational Plans

As was discussed above, the user may associate one or more operational plans with each command entity in the command structure. For example, the Strike Warfare Commander (STWC) in a specific task group will have a strike plan for each operational phase of a strike to be simulated. These phases might be designed to suppress coastal defenses, suppress inland defenses, strike primary targets, collect battle damage assessment (BDA) data, etc. Similarly, the undersea warfare commander (USWC) in a specific task group will have a plan for each USW operation. These USW operations might include air-, surface-, or subsurface-based area search and surveillance, barrier patrol, SPA prosecution, mine laying, mine hunting, mine clearance, collection of indications and warnings (I&W) data, special operations (SPECOPS), and others.

Each operational plan is of a well-defined type characterized by timing data, attribute data, and responsive tactics tables. For example, an air-based area USW search mission plan will include specification of search start and end times, search area, search method, search sensors, and other search parameters which may include buoy patterns, buoy duration, search altitudes and speeds, etc. Responsive tactics tables are used to augment the basic plan and to allow for dynamic planned responses to specific trigger conditions (e.g. attack targets of opportunity, evade unanticipated threats, report observed threat activity, etc.). The responsive tactics table format is illustrated in Table 7. A specific responsive tactics table might be associated with an air-based area USW search mission, and as such, it would be used to provide the air search platform commander with responsive actions to take given the detection of threats or contacts of various types. In this example, each trigger condition might correspond to the detection of specific threat types (e.g. SS, SSN, etc.) and the possible platform responses might be to report the contact and/or to prosecute the contact. Each response may be assigned a priority and (possibly multiple) criteria. The priority in the case of a reporting response represents message priority (e.g. 1-flash, 2-alert, etc.). The criteria in this case defines under what conditions the report response is to be executed (e.g. all, when within range R, when surfaced, etc.). Similarly, each contact prosecution response may be assigned a priority, (possibly multiple) criteria, and a prosecution

Dynamic Tactical Response Table				
{COMMANDER TYPE, TRIGGER TYPE}				
Operational Applicability	{Commander Subtype(s) and/or Instances(s)} {Command & Control Mode(s)} {Mission Type(s)} {Attack Readiness Condition(s)} {Scenario Time Interval(s)} {Scenario Phase(s)}			
Tactical Trigger Conditions	Dynamic Responses			
	Response Type 1	Response Type 2	•	Response Type n
{Condition Set 1}	{Priority; Criteria; Action(s)}	{Priority; Criteria; Action(s)}	•	{Priority; Criteria; Action(s)}
{Condition Set 2}	{Priority; Criteria; Action(s)}	{Priority; Criteria; Action(s)}	•	{Priority; Criteria; Action(s)}
•	•	•	•	•
{Condition Set n}	{Priority; Criteria; Action(s)}	{Priority; Criteria; Action(s)}	•	{Priority; Criteria; Action(s)}

Table 7. Responsive Tactics Table Format

action. The prosecution action specifies the manner in which the prosecution is to be conducted (prosecution platform type, number, and prosecution tactic) given that the criteria are met. These generalized tactical response tables have proven in NSS and predecessor models to be widely applicable to force- and unit-level decision-making in the air-, ocean surface-, undersea-, and land-based problem domains.

3.6.3 Plan Execution

As was described above, operational plans are associated with specific commanders. Operational plans also typically include timing data, i.e. data specifying when in simulated time (or under what conditions) the commander is to execute the plan. In the example alluded to above, the USW commander (USWC) would initiate the air-based area search mission at the user-specified time by requesting the allocation of subordinate air assets (from the cognizant Group commander) to the mission. If insufficient assets were available, a lower priority mission would be canceled or delayed or the area search mission in question would be canceled or delayed. Given that sufficient air assets were (eventually) available, the selected air assets would transit to the search area and conduct search operations as specified in the area search plan. At any time during each aircraft's flight, the aircraft may either receive tactical information (via its on-board communications suite) or generate tactical information (via its on-board sensor suite). Both received and internally generated tactical data is fed into the aircraft's tactical picture processor. Newly received and processed tactical data can result in the generation of a new track or an update to an existing track. In either case, this can lead to a responsive tactics table **trigger**, i.e. the new or modified track can cause the area search platform to responsively report the track; to responsively engage the track; or to responsively request another platform to engage the track. NSS includes operational plans and responsive plan execution logic for many, if not most, Strike, Surface Warfare, Air Warfare, and Undersea Warfare mission areas. Some elements of Land Warfare are also included.

4.0 Open Issues

Though not emphasized in the above discussion, it has been our experience that the C2 representation approach described above is best suited to the representation of unit- and force-level tactical decision-making. Theater- or campaign-level decision-making, such as a CINC's responsive change to high-level objectives or plans, is probably beyond the scope of this approach. Part of the reason for this is that campaign-level decisions in the real world are often influenced by factors (political, economic, etc.) which are seldom, if ever, represented in Military simulations. For this reason it is perhaps doubtful that there is utility in simulating such decisions constructively. NSS currently can only represent decisions of this type in a scripted fashion. It may be that permitting man-in-the-loop interactions, for systems capable of running in a single replication interactive or virtual mode, is the only practical way to deal with the representation of decision-making at the theater- or campaign-level. More work is required, however, to settle the issue of exactly what subset of all Military decision-making activities are realistically addressable in constructive simulations.

As was discussed above, NSS employs a dynamic trigger and response mechanism for representing various intelligence collection and response processes. It is an open question whether this relatively simple user-defined table-driven approach is adequate to represent the full spectrum of highly multi-data-source, highly cognitive, intelligence collection and assessment processes. It is our tentative conclusion that more advanced cognitive modeling paradigms are likely to be required in this area.

Joint service, multiple warfare operations are ones in which resource contention is a primary concern. In actual Military operations, the resolution of such resource contention problems can involve the complex interactions between multiple commanders and the software/hardware tools that support them. In NSS we have attempted to distill this complex manpower-intensive process into the warfare mission area (WMA) priorities table pictured in Table 6. This table can account for time variations and conditional variations in these priorities. Nevertheless, one might very reasonably ask whether such a relatively simple mechanism can capture the essence of what is typically a highly

complex resource allocation problem (e.g. the allocation of assets within a multiple carrier battle group – CVBG). More study is required in this area.

A final very significant issue is that of traceability; i.e. how does the Military analyst assess the impact of alternate decision strategies on the simulated outcome? What is ultimately required is the ability to compute the marginal impact (expressed in terms of the magnitude of change in high-level measure(s) such as number of threats killed) given unit changes in key C2 input parameters. Such a marginal impact assessment capability could, for instance, trace the effect of increased timeliness or accuracy of specific tactical data products on high-level outcome statistics such as the number of threats killed. This capability is analogous to the well-known *shadow price* or *reduced cost* statistics provided by linear programming packages. Unfortunately, there is no automated discrete event simulation analogue to these linear programming concepts. NSS permits the analyst to pre-define excursion cases and to automatically execute and plot the resultant sensitivities. These excursion sets must be pre-defined and run in a brute force manner, however. Research in the area of developing methodologies for automating computationally efficient sensitivity analyses in discrete event simulations is needed. Any progress in this area would yield enormous payoff.

5.0 Future Work

As alluded to above, there are numerous unresolved or partially resolved issues relating the representation of C2 and C2 processes. In addition, there are several noteworthy areas where new work is required. One such area concerns the development of automated tools for generating and reading Joint operational plans (OPLANs) in standardized formats. To the extent feasible and practical, models and simulations should accept Military OPLANs of all types as input in order to streamline the process of scenario file construction and to facilitate the evaluation of actual operational plans. Standard electronic formats for Joint OPLANs of all types are required as are the software tools for inputting and outputting these files in the accepted formats.

Given the Military's increasing reliance on commercial-off-the-shelf (COTS) technologies for C2, the areas of information operations (IO) and C2 warfare (C2W) are bound to be areas of great concern for years to come. IO and C2W present numerous new M&S challenges as discussed in Appendix A. While the explicit treatment of information collection, dissemination, and processing and its impact on the commander's decision process as represented in NSS is a good starting point, more work is required to provide a sufficiently complete and robust representation of the IO/C2W environment.

Finally, despite all of the research and development that has focused on artificial intelligence (AI), knowledge engineering and acquisition (KE/KA), and related fields, there is no clear consensus within the Military M&S community concerning the utility of these technologies. More work is required to assess the technical trade-offs between the comprehensibility and simplicity of low technology options (such as decision tables) and the generality and flexibility of higher technology options (such as formalized rulebases, neural nets, etc.). A suitability and cost assessment of the various representational technologies for classes of decision-making problem domains is needed.

6.0 Summary

The representation of command and control (C2) and command decision processes, through the use of modeling and simulation (M&S) techniques, has become a key element of Department of Defense (DoD) technology initiatives in the areas of analysis and acquisition, operations planning and execution, and training. The next generation of DoD sponsored Military simulations needs to accurately simulate C2 and related command decision activities as well as the impact that deep sensors, communications, and information flows have on these processes. The Naval Simulation System (NSS) is an example of a next-generation Military simulation which provides a fully integrated and comprehensive treatment of: (1) command structures and relationships; (2) representation of operational plans; (3) simulation of plan execution including dynamic/responsive asset allocations; (4) tactical picture generation; (5) dissemination of surveillance and intelligence products; and (6)

simulation of surveillance and intelligence product collection. Though more work remains to be done, NSS is a good first step toward accomplishing the C2, IO, and C2W representational goals stated in this paper.

Appendix A: IO and C2W Overview

Information Warfare is defined as "any action to exploit, manipulate, or destroy an adversary's information and/or information systems while leveraging and defending friendly information and information systems to achieve information dominance" [Sabalos, 1995]. Command and control warfare (C2W) is defined in the JCS Memorandum of Policy 30 as the military strategy that implements IO on the battlefield. Both IO and C2W employ five "pillars" to get the job done:

- Electronic warfare (EW),
- Psychological warfare (PSYOPS),
- Operational security (OPSEC),
- Physical destruction, and
- Military deception.

All of these actions, supported with intelligence, are designed to cause confusion and disrupt an adversary's decision cycle to the point that hostilities are either avoided or the fight is accelerated to a rapid and definite conclusion. In essence, IO is a force multiplier for every weapon in the services' inventory.

IO can be broken into two subcategories: offensive and defensive. OPSEC currently encompasses the entire scope of defensive IO. It is the daunting job of protecting our own information systems from foreign intrusion. This is fast becoming an impossible task given the military's increasing reliance on commercial networks and COTS hardware and software. One approach is to use a specialized group of computer hackers called the Red Team to attempt to exploit computer systems on military facilities. The Team can usually point out where the facility's vulnerabilities lie, both by breaking into the system and by doing so most often undetected by normal users. In theory, this approach could be used to test operational forces' weaknesses, but there is no mention of a program to implement this at this time.

Offensive IO is the classic attack on targets to cause confusion and disrupt the flow of command, control, and information within an adversary's infrastructure. Targets of offensive IO include political, military, physical, and economic infrastructures. Here are examples of each category:

- Military
  - Intelligence sensors (subject to jamming, spoofing, and precision strikes),
  - Data processors (data can be corrupted or deleted to hinder force tracking and logistics, for example),
  - Decision aids (subject to same attacks as data processors), and
  - Communications networks (subject to precision strike, spoofing, and jamming).
- Economic
  - Payroll records (subject to deletion or corruption), and
  - Financial databases (subject to same attacks as payroll records).
- Political
  - Any records kept by the government (subject to corruption or deletion), and
  - Communications between a country's leaders and the military (subject to physical destruction and/or jamming).
- Physical
  - Public telephone switching systems (subject to destruction or tampering),
  - Public utilities such as power (subject to same attacks as telephone systems), and
  - Air traffic control systems (affecting public safety).

Examples of IO successes in Operation Desert Storm were the use of precision strike cruise missiles to take down the Iraqi IADS and C2 infrastructure early in the war; use of PSYOPS leaflets dropped on Iraqi troops to convince them

to surrender; jamming of communications and EW radars by Compass Call and USN EA-6B aircraft; use of a "phony" amphibious force in the Persian Gulf to distract Iraqi forces from the true Allied Ground Offensive (deception); and OPSEC which kept our plans relatively secure from Iraqi intelligence.

Appendix B: The Naval Simulation System

The Naval Simulation System (NSS) is a next-generation, object-oriented, multiple-warfare simulation system which represents C2 and C2 systems in a fully integrated and comprehensive fashion. This representation of C2 processes and systems specifically addresses: (1) command structures and relationships; (2) representation of operational plans; (3) simulation of plan execution including dynamic/responsive asset allocations; (4) tactical picture generation; (5) dissemination of surveillance products; and (6) simulation of surveillance product generation. We believe that an NSS-like capability is highly supportive of the C2, IO, and C2W representational requirements addressed in this paper.

NSS was created to overcome the problems associated with trying to simulate the many components of campaign level warfare with a combination of different models, each representing different parts of the campaign. Problems arise because the different models used are typically developed under different conditions for different purposes with no specific concern for compatibility or the ability to achieve effective inter-operability while running at processing speeds sufficient to represent days or weeks of warfighting time with only hours of computation time.

Prior to the development of NSS there were two approaches for dealing with this problem. One approach was to use analysts to review the information from the different models and combine the information manually to achieve the representation of the combined campaign level warfare. This approach has the merit of review by expert analysts, but is relatively cumbersome and slow. The other approach has been to develop models that group many effects together into low resolution, or highly aggregated, views of the campaign level warfare. While this does achieve simulation of the broad scope of campaign warfare in a single system with an acceptable processing speed, the low resolution view is unable to address important analysis questions (such as those concerning C2, IO, and C2W) which depend upon details of the interactions between warfighting components. The quality of the results from such aggregated analysis depends strongly upon the skill of the analyst to make the right choice of what information to treat explicitly, while representing most interactions at sufficiently low resolution to achieve the desired fast execution.

Within the last two years, each of the services and DARPA have initiated efforts to exploit emerging technologies in object oriented software development and higher speed computers to develop higher resolution, more detailed simulation systems to achieve faster analysis, or training, with explicit representation of sufficient details to provide "realistic training" and more detailed analysis. The Air Force has initiated development of the National Air and Space Model (NASM) primarily for training, and is considering the re-implementation of THUNDER, a key analysis model used by the Air Force Studies and Analysis Agency, in a modern object oriented software architecture. The Army has initiated the development of WARSIM 2000 for training, and its Concepts and Analysis Agency is upgrading ARES to a more advanced object oriented software architecture. DARPA has a very large effort to produce a Synthetic Theater of War (STOW) capability using high speed computing to achieve sufficiently detailed representations of key warfighting platforms to provide realistic training for Joint Forces. The Naval Simulation System (NSS) is the core of the Navy's thrust to exploit modern software architecture and higher computation speeds to bring more details to campaign level analysis.

In 1995 the Department of Defense Modeling and Simulation Office (DMSO) initiated a major effort to achieve inter-operability between the emerging advanced simulation systems. DMSO formed an Architecture Management Group (AMG) to define and prototype a new architecture that will provide a very general means of achieving inter-operability between simulation systems that were developed using different internal software architectures. This is called a High Level Architecture (HLA) for inter-operability. The Naval Simulation System is a

member of the DMSO Architecture Management Group, along with the other major new service and DARPA systems identified above. Some major service legacy systems with less advanced architectures are also involved. These include the Navy BFTT program. DMSO also included the two major new Joint simulation system developments - Joint Simulation System (JSIMS), and Joint Warfare Analysis System (JWARS). Thus NSS is a key representative of Navy modeling and simulation in this major DMSO inter-operability initiative.

It should also be noted that there is another problem that has plagued the application of Modeling and Simulation to both analysis and training systems. This problem is the lack of standards for authoritative representation of both friendly and hostile warfighting systems. Multiple models developed separately typically use different analysts, or data sources, to determine critical input data values. The services and the Department of Defense (DoD) Joint simulation activities have had no means of resolving differences among expert opinions about the appropriate data values. In the last year, DMSO and each of the services have begun vigorous initiatives to achieve authoritative review of the representations being implemented in the new software and computation architectures. For Navy systems, the Naval Doctrine Command is coordinating a fleet review of input data and system representations in STOW, NSS, and the simulation part of the BFTT program.

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Co-Evolving C^2 Organizational Processes, Decision Support Technology, and Education/Training: the Role of Evaluation in Cognitive Systems Engineering

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1. Collaborative Decision-making in Complex, Dynamic Environments

Military operations during the last thirty years have shifted from conventional modes of warfare with well-understood adversaries towards warfare characterized by shorter warning times, greater ambiguity and the requirement to plan and execute responses in a greatly reduced time frame. While dramatic innovations in technology significantly extend information processing capabilities, the critical – and often the most vulnerable – components in command and control (C^2) systems remain the human decision makers. As advanced decision support technologies permeate operational units, today's military forces face tremendous challenges in simultaneously evolving effective organizational processes, education and training, and advanced information technology. The increased pressure on C^2 systems emphasizes the need for more comprehensive "decision system" modeling relating the multiple components of C^2 decision making to system effectiveness.

1.1 Realizing the Value of Information as a Force Multiplier

The current direction in C^2 systems envisions worldwide information exchange linked by local systems to the warfighter to permit the flexible exercise of initiative while maintaining situational awareness across the span of command. Emerging in these models is the notion of *effective* and *efficient* C^2 process as a "force multiplier" with the potential to impact battle outcome as significantly as advanced weaponry. Realizing the potential impact of information in the C^2 process depends upon the organization's ability to employ C^2 technology effectively. Thus, "having more C^2" is not an assurance of success in warfare. Increasing data collection and dissemination through advances in sensor systems and data communication has resulted in the delivery of overwhelming volumes of raw data and information products to decision makers without significantly improving their timely use of relevant information to achieve organizational objectives. For example, analysts are currently able to process only a fraction of the sensor data captured; an even smaller portion is actually used in decision-making. Information overload spawns decisions based on the evaluation of only a portion of the available information. The key benefit of information technology (IT) for C^2 support is the ability to present the decision makers with the timely information in a rapidly comprehensible form.

1.2 Sharing Situational Images and Decision Information

Future warfighting doctrine suggested by proponents of "rapid dominance" hinges upon the technology-enabled ability to quickly establish complete control of the battlespace (Ullman & Wade, 1996). The vision for the next generation of C^2 systems seeks this dominance through smart munitions, faster and longer-range weapons, superior sensors, fully linked communications, and the requisite tactics, techniques, and procedures (TTP) to employ these capabilities in controlling the battlespace. Most formal and informal assessments of combat performance emphasize the importance of two central tenets of combat effectiveness: *maintaining battlefield awareness* and *synchronizing actions*. Dominance in warfare is achieved by combat units whose key team members rapidly develop a shared understanding of the current situation, communicate it to their subordinate units, and coordinate a tactical response within the horizon of opportunity (Alberts, 1995).

A fast, synchronized response in the complex, dynamic environment of modern warfare depends upon rapid situation assessment from reliable intelligence coupled with almost simultaneous communication to all units. In order to support rapid situation assessment, the information technology infrastructure in place and in planning produces an overwhelming volume of information delivered in an unrelenting stream to the operational end-user. The ensuing information deluge may paralyze the users/warfighters or bury critical intelligence in the "noise." To build C^2 systems that provide usable information to decision makers, we must understand and support the command and staff processes for interpreting sensed data, generating courses of action, and coordinating responses.

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Battle synchronization depends upon the "transparent" flow of information to facilitate collaboration, communicate the commander's intent to operational forces, and incorporate feedback on progress of operations. Information systems that only address the requirements of organizational sub-functions (e.g., planning or logistics) deform the C^2 process, impeding or blocking information flow among functions and eliminating the benefits of advanced IT. For example, the potential value of information for offensive and defensive information warfare remains unrealized when information operations are not integrated into the warfighting processes and decisions. To achieve the full potential of information dominance, C^2 system design must support the organizational function and process integration required for rapid and continuously responsive organizational information processing.

2. *Supporting Decision Makers with Advanced Information Technology*

2.1 Understanding the Role of Information in Decision Making

Since the earliest writings on command in warfare, military strategists have attempted to characterize the commander's information requirements with respect to dimensions such as timeliness, degree of certainty, level of detail, and other aspects. Literal interpretation of "common operational picture" might imply that everyone must see the same images. In contrast, a decision-centric view of information requires varying uses of the same data to best address the scope of responsibility and task requirements. At each level in the C^2 hierarchy, decision makers develop their situational images from multiple views of the battlefield (i.e., tabular data, mission flow charts, maps, and sensor displays). Information layering at the senior command level presents battle information at a high level with minimal detail, tailored to match decision requirements and individual preference. In this model, information is provided to the commander and other decision makers based on its value in maintaining situational awareness and its relevancy to the operational decisions rather than data availability. This approach may support better decision-making performance by reducing overload and better C^2 system performance through improved bandwidth allocation.

Command and control systems are often mistakenly identified as the electronic subsystems that support decision making or assist in implementing those decisions. More accurately, command and control systems integrate the human operators and decision makers, organizational structure, doctrine and procedures, information processing systems, equipment and facilities to support command authority at all levels to accomplish the objectives of designated missions. The various components of this "decision system" are linked such that changes in one of the human, machine, or human-machine roles can significantly modify or affect the tasks performed by the other roles. Furthermore, systems operate within environments that include not only superior organizations and related units, but also a dynamic array of potential adversaries and organizations of dynamic allegiance. Finally, geographic location and associated climatic conditions also define the environments. Meaningful evaluation of the potential effects of introducing new decision aiding technology into a C^2 decision system requires the understanding of purposive context of that system's operation. Research and development efforts must focus on innovative methods to model decision process and use analysis of relationships between decision-making process and technology to support system design evolution.

The key to effective problem definition is finding a means for creating and relating *multiple* models, or views, of the problem. Byrd *et al* (1992) survey eighteen requirements analysis and knowledge acquisition techniques that facilitate problem domain understanding in terms of information requirements, process understanding, behavior understanding and problem frame understanding. They emphasize that no single method is suitable for eliciting and modeling all the dimensions of domain knowledge. Moreover, when the problem is complex and multi-dimensional, the design team needs methods specifically designed to facilitate interdisciplinary thinking. For example, multi-perspective context models, such as those described for problem analysis in Davis (1993), assist in creating informal models for review and iteration with the sponsors and operational users. Similarly, Zahniser (1993) describes the creation of *N*-dimensional views of the system developed by cross-functional development teams. The process is designed to encourage innovative thinking and bring multi-disciplinary experience to bear on system development problems. Figure 1 presents a metamodel suggesting the various models that describe and define the organizational decision system.

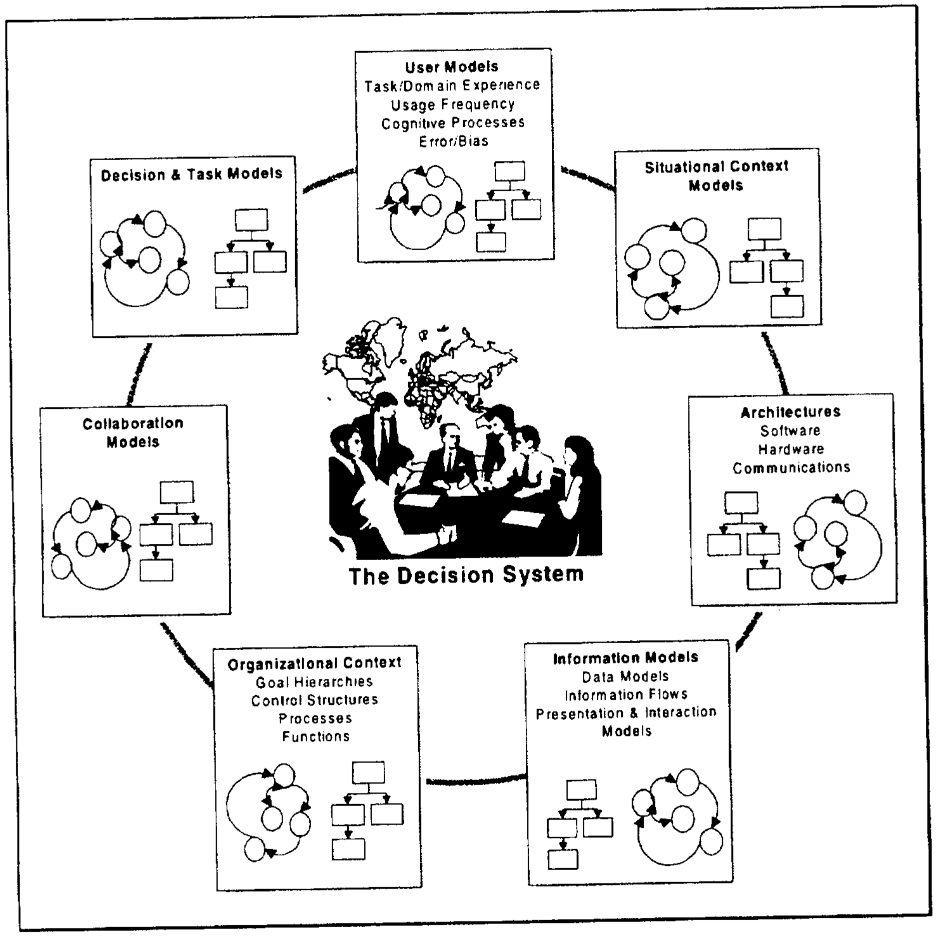

Figure 1: Multiple Models Defining an Organizational Decision System

The component models that comprise the decision system reflect research and practice from multiple disciplines. Some of the models have established semantics within their parent disciplines; others are still being developed. Perhaps more critical to their application, there are few well-defined links between models and/or components. For this reason, the state-of-practice is still multi-disciplinary, rather than inter-disciplinary. Rouse (1982) compares the disciplinary perspectives on problem solving in terms of three dimensions: the age of the discipline, the nature of the phenomena investigated, and the nature of the intellectual world in which the discipline is applied. The discipline of systems engineering necessarily crosses boundaries to connect these disciplines. In addition, the management, cognitive, and behavioral sciences include many advocates for holistic approaches to understanding the multiple facets of organizational decision making. These cross-cut concepts such as:

- Training & Learning
  - situated learning (cf., Suchman & Trigg, 1991)
  - learning organizations & knowledge management (cf., Choo, 1998; Senge, 1990; Shein, 1992)
- Process Modeling & Improvement
  - software process improvement (cf., Humphrey, 1989)
  - organizational process re-engineering (cf., Hammer & Champy, 1993; Hammer & Stanton, 1995)
  - process modeling for re-engineering (cf., Yu & Mylopoulos, 1993)
  - IT-enabled change (Manzoni & Angehrn, 1998)
- Cognitive Systems Engineering
  - user-centered design (cf., Norman & Draper, 1986)
  - decision-centered design (cf., Andriole & Adelman, 1995; Ehrhart & Aiken, 1991; Woods & Roth, 1988)

- collaboration support & situated design (cf., Olson & Olson, 1991; Greenbaum & Kyng, 1991)

These approaches model humans and technology support in organizations as "organic" to information processing, knowledge-creating, and decision-making processes.

2.2 Technology for Collaborative Decision Support

Evaluating the decision support component of a C^2 system within the context of the overall system development goals is extremely difficult. Because of the complex interactions among humans, equipment, and information within the organizational structures and procedures, the contribution of the decision aiding design to overall system performance cannot be expressed in terms of a simple, direct metric. Modeling C^2 system designs requires an understanding of the interactions among the system components (users, equipment, tasks, organization and procedures), the missions and functions the system supports, and the situational and environmental factors which affect those missions. Cognitive systems engineering (CSE) supports decision-focused information technology development by:

- Maintaining development focus on the operational decision task requirements;
- Synthesizing tools & methods across multiple disciplines, including artificial intelligence, cognitive science/psychology, sociology, organization science, systems engineering, and operations research;
- Representing complex, dynamic environments by developing and integrating multiple domain models and multiple kinds of models; and
- Supporting human-machine cooperative problem-solving and decision-making.

3. Applying Cognitive Systems Engineering Methods to Train and Support Collaboration in Critical Decision Environments

3.1 Human-Machine Cooperation in Complex, Dynamic Environments

Decision makers derive meaning from incoming information by creating, evaluating and selecting causal explanations or assessment of the possible situation to account for the information. Accuracy of monitoring, focus of attention, and processing activities affect situation assessment performance. In addition, performance depends upon memory of the evolving context, previous experiences, and training to identify relevance and interpret incoming information. The human ability to perceive and interpret information based upon context is an essential strength in situation assessment. When decisions must be made in high threat, dynamic environments, contextual interpretation permits the decision maker to make accurate assessments intuitively and respond rapidly. Context misinterpretation, however, has also been a factor in disastrous decisions. The two commonly cited examples are the erroneous shooting of the Iranian Airbus in 1988 by the *USS Vincennes* (Helmreich, 1988) and the April 1994 shooting of two US Army UH-60 Black Hawk helicopters by US Air Force F-15C fighters (Harris, 1994).

Several cognitive factors impact situation assessment and decision-making, including the effect of time pressure, attention requirements, the quality of available information, and complexity of the problem. Each is discussed briefly below.

3.1.1 Time Pressure

Decision-making in time critical environments is an inescapable part of modern warfare. The speed and range of the new generation of weapons systems and sensors demand ever-faster information processing by C^2 systems and their users. The decision horizon in military operations is determined by the time available to make a decision and the nature of the task or function supported by the decision. Time pressure effects both the process and quality of decision-making by impacting the inference and reasoning strategies chosen by decision makers. Thus, system designers must consider inference-making requirements for tasks such as information interpretation. Stress associated with a shorter decision horizon results in general narrowing of perceptual focus ("tunnel vision") or issue fixation, rendering decision makers less capable of dealing with multiple stimuli/issues. To compensate, decision makers will adapt task performance and reasoning strategies to meet the time requirements. A decision maker may decrease the number of information sources used in situation assessment, the number of alternative courses of action considered, and fail to critique the micro-decisions that aggregate to a larger, central decision.

Eisenhardt (1989) examined decision-making in organizations operating in "high-velocity environments" where the decision context and technology are changing so rapidly that "the information available is poor, mistakes are costly, and recovery from missed opportunities is difficult." Fast, successful decision makers do not limit their information seeking and analysis to save time; in fact, many of the fast decision makers use more information than their slower counterparts. The difference is in the types of information sought and used. Slow decision makers rely on planning and future-oriented information and tend to generate fewer alternatives, examining each in depth. In contrast, fast decision makers speed decision making without sacrificing decision quality by the following techniques:

- Focus on real-time (operational) information about the current situation
  - track operational indicators (measures of performance);
  - share information in frequent operational meetings;
  - seek advice from experienced, trusted leaders.
- Develop several alternatives, but examine them quickly by comparing them with each other.

When time pressure increases, errors result as decision makers trade off performance accuracy to meet response speed requirements. Expert performance in these domains applies "automatic" responses to recognized situations. Training and experience are critical for developing the basis for both recognition and response. As the decision horizon shortens, experience increases the decision maker's ability to focus attention on relevant information and reduce the workload required to evaluate complex information. System support for time-critical tasks should highlight relevant information and filter out irrelevant information to facilitate "at a glance" processing by the operator or decision maker. In addition, the concept of operations involving the new systems must optimize task allocation between human decision makers and automated support systems.

3.1.2 Attention Requirements

Situational awareness requires varying levels of vigilance depending upon the dynamics of the environment. Therefore, the attention requirements associated with a decision task may involve little active monitoring, monitoring at intervals, or continuous monitoring of the situation. Attention is also related to the difficulty of detecting an event or stimulus. Environmental stimuli that are very difficult to detect, either due to inherent characteristics or the presence of other stimuli (noise) may not attract attention during monitoring. In these cases, machine monitoring for detection or enhancement can facilitate perception or focus attention. In addition to the cognitive resources demanded by the attention requirements, the pacing and volume of incoming decision data increase demands upon the decision maker's short-term memory. For the system designer, these impacts must be evaluated in terms of whether the typical memory demands exceed the capability of proposed users. At the lowest levels, the pace and volume of incoming information are manageable by the average trained user. As the demands are increased, only highly motivated experts can manage the flow of information. The expert uses domain and task knowledge to cluster information in meaningful "chunks" rather than as discrete elements. At the highest levels, the volume of information overloads human ability to absorb and manipulate. At this point, machine monitoring and pre-processing is required to aggregate information into more manageable forms.

3.1.3 Information "Quality"

The qualitative characteristics of the available information affect the extent to which it may be interpreted correctly and applied in problem solving. When intelligence is incomplete or ambiguous, decision makers may focus on irrelevant information and inappropriate causal explanations. Decision makers may be unaware that critical information is missing and need reminders or models that call attention to missing, imprecise, or ambiguous values in relevant stimuli. For example, the timeliness and reliability of system updates during task performance serves as feedback to inform the decision maker about the appropriateness and efficacy of the response. Delayed feedback is often misinterpreted or incorrectly associated with the wrong response causing the decision maker to construct invalid causal models of the task and domain. When feedback is variable in quality or delayed, the effects propagate through a network of dependent choices making the reliability of task performance unpredictable. Similarly, forcing decision makers to work with information at the wrong level of abstraction can either over-burden them with unmanageable detail or provide them insufficient information to adequately assess the situation. For example, when the information display and interaction designs for systems focus on the individual operators, successful use by the command team will require re-configuration to adapt the display and interaction to distant viewing. Strategies for analytical support and information presentation require an understanding of which data elements may vary in information reliability and how potential variation may affect interpretation.

3.1.4 Problem Complexity

The complexity and tractability of a decision problem are affected by problem characteristics, such as:

- Number of feasible hypotheses that may be generated to explain the available information or the number of possible responses; and
- Number and relationship of the factors which must be considered in evaluating each hypothesis or response.

In closed decision spaces with few alternatives, decision-making is usually performed with rule-based, procedural reasoning. Decision errors in such instances result from selecting an inappropriate or flawed evaluation rule. In situations where the number of feasible explanations for available information may be large, decision-making may be unacceptably delayed as decision makers wrestle with the possible consequences of possible courses of action. In complex environments, the network of uncertainties rapidly becomes intractable for human evaluation, often leading decision makers to simplify with insupportable inference leaps. Decision makers often use cognitive short cuts, or heuristics, to rapidly reduce complex relationships into a loosely integrated general assessment. Decision errors often stem from a deadly combination of wishful thinking, incomplete intelligence, and latency in the updating of information. Decision makers may also avoid committing to any option, often waiting to see if changing events force or suggest a choice. In such cases, the underlying assumptions may never be integrated adequately for evaluation. Designs for C^2 support systems must provide decision makers the means to comprehend and act within the complexities of the battlespace to achieve mission objectives.

3.2 Improving C^2 Decision System Effectiveness

The success of C^2 support systems depends not only upon their computational speed and robustness, but also whether the designers have adequately supported the cognitive demands of the users' tasks and the impacts of technological change to the organizational processes. Human-computer decision-making performance in critical situations is dramatically affected by the design of the user-computer cooperation (e.g., task allocation, information sharing requirements, etc.) with respect to the environmental characteristics (e.g., complexity, uncertainty, dynamics, level of threat, etc.) and the response requirements (e.g., timing and precision). Woods and Roth (1988) propose that mismatches in the system design involving these factors result in the ineffective use of resources and, in the worst cases, disastrous system errors and failures. They cite several cases where automation degraded rather than improved performance due to user-related design failures such as a lack of support for supervisory control requirements and decision-making strategies, and failures to anticipate the organizational impacts of technological change. This section presents several aspects of system design that can improve the overall effectiveness of the collaboration between human decision makers and their C^2 system supports.

3.2.1 Representing Uncertainty in Current Information

Uncertainty impacts decision performance when the information required for decision-making is incomplete, inaccurate, imprecise or ambiguous. It is often the case that decision makers are presented with sets of information with various levels of certainty. For example, most of the details on the location of friendly forces will be complete and accurate. In contrast, the details on the opposing force may be very precise in one area and sketchy in another due to the available intelligence. Mixing information without certainty indications can lead in general distrust of the information system or, conversely, unwarranted trust in imperfect data. Therefore, it is important to provide decision makers with tools and methods to understand the information that forms the basis of their decisions. This can be done with displays and also with decision aids that highlight the information that may be questionable. When linked to decision points, these tools can also aid in the determining the critical information requirements for tasking intelligence gathering.

3.2.2 Designing for Reliability

To be effective C^2 systems must be reliable – the systems must be available upon demand with current information. The best case is 100 percent reliability; the worst case is multiple failures in critical systems. The most likely case is that there will be some disruption of services and delays in information updates. Decision systems fail in a variety of ways. Van Gigch (1991) lists five types of system failures:

- Failures of structure and control - reliance on faulty controls built into the structure of the system; expecting other parts of the system to catch mistakes or take care of problems;
- Failures of technology - technology that does not perform as expected; provides incorrect, incomplete and/or

imprecise information;

- Failures of decision processes - flawed assumptions and biases that effect judgment and choice;
- Failures of behavior - doing the wrong thing; and
- Failures of evolution - rigid, non-adaptive behavior.

The engineering response is to build in "graceful" degradation so that failure of one subsystem does not propagate multiple failures. Information about the effects of outages is provided in cryptic form for system administrators – but the users are left to fend for themselves. Users need clear, understandable information about the extent to which their current information may be impaired by system outages or delays. For example, the negative impacts on decision maker confidence may be reduced by providing feedback, such as:

- Information currency indicators (e.g., update timestamps and icon "aging");
- Summary of update times & content; and
- Overview diagrams of systems affected by delays and failures.

Operators may need assistance in identifying what information must be restored to bring the system up to date. Finally, decision makers need to be alerted when systems or networks are unavailable. Ideally, this information would also be represented in the certainty factors for information in dependent systems. For example, if the intelligence systems supporting the enemy situation displays were impaired, the predicted or last known location could be displayed with a change in the icon that indicated its position was not based upon direct sensing or recently updated information.

3.2.3 Synchronizing Processes & Systems to the Pace of Battle

Time pressure in combat usually is associated with a general increase in the pace of battle. The number of decisions and the frequency of decision cycles increases as decision makers feel "impelled" to action by the tempo of the battle. Unfortunately, the stepped-up tempo of operations can negatively impact communication across the force and disrupt the synchronization of the battle. Several factors seem to define the organizational synchronization at any level:

- **Leadership** - The importance of leadership in battle synchronization is a central tenet of military training and doctrine. Systems and process designs that interfere with coordination activities can undermine the commander's synchronization efforts. The appropriate roles of information technology in supporting that leadership are still evolving.
- **Communication** - Communication within the command post or among tactical team members increases dramatically during the critical phases of an operation. Increased communication requirements within and between units can result in excessive bandwidth demands or failure to maintain coordination among all units. Moreover, it can be almost impossible to predict the contribution of individuals or units who are "out of the loop." Thus, as battle tempo increases, there is an increase in the uncertainty about the outcome due to communication lags.
- **Training** - C^2 systems can aid in extending understanding – or confuse and undermine training and experience. The commander and staff continue the soldier learning during exercises by explaining situations and providing examples of alternative interpretations.
- **Systems** - Uneven automation or system performance results in unsynchronized operations or synchronizing to the lowest common denominator. Information systems should support training and experience by reinforcing and extending learning.

Operational coordination on the modern battlefield relies on the synchronization of human processes and system supports. In distributed environments, this coordination depends not only upon the degree of synchronization required and delivered, but also on the means by which all concerned units understand their responsibility and status within that coordinated activity. Commanders and staff need automated supports for assessing the overall synchronization of effort and predicting the effects of individual system and unit performance variation. This may be accomplished with graphic aids such as dependency charts or diagrams that indicate the planned synchronization and the current status of units. Further support to the commander may be provided through analysis tools that assess the impacts of the current trends on the expected outcome. This affords the commander a valuable projection capability to focus contingent planning activities and resource allocation.

3.2.4 Supporting Visualization and Manipulation of Objects in the Decision Space

One of the most difficult aspects of C^2 decision-making is the sheer number of mobile entities that define and affect the course of battle. Commanders and decision makers use training and experience to filter and structure battle information. The way decision makers are presented and allowed to interact with information is a crucial factor in their ability to collaboratively construct and share a common understanding of the situation. While the operators have some ability to manipulate digital objects at workstations, the command team still does not have the digital equivalent of the interaction possible at wall maps. Similarly, the white board technology is insufficient to support the same level of representation possible with colored pens on a traditional whiteboard. In contrast, command decision makers respond enthusiastically to prototype aids that permit them to see a plan "play out" regardless of whether the system has any underlying knowledge of that plan. All these examples suggest the need to examine the display and interaction concepts for the major systems based upon a profile of the various users and what decision tasks and cognitive processes they are performing.

3.2.5 Providing Automated Decision Aids

In the last 30 years, the U.S. Dept of Defense has contracted for a range of automated decision support tools. Most of these were designed and prototyped with guidance from tactical experts. The vision for the evolution of the future systems incorporates some of the knowledge gained from these efforts; yet the advanced warfighting experiments present systems with few automated decision aids. Most aids remain confined to simple table look up functions for very structured, well-bounded problems. Despite considerable computing power, we are still seeing users (including commanders) constructing their own manual decision aids. Such manual aids include simple lists and graphics to assist in managing complexity of decisions. The fielded planning tools lack COA evaluation capabilities to project the outcome given current information. Such capabilities when added will greatly enhance the ability of the planning team to advise the commander on plan contingencies and the related intelligence requirements for tracking the execution of the plan.

3.3 Determining Cognitive Requirements for C^2 System Design

Human-computer decision-making performance in critical situations is dramatically affected by the design of user-computer cooperation, including task allocation and information sharing requirements. When human decision makers and operators collaborate with computer-based systems, the design of those systems will determine the extent to which the users will be able to employ the functionality the systems provide. System developers must consider design options with respect to the characteristics of:

- Users (training and experience),
- Users' tasks and organization's tasks,
- Organizational mission, structure, and processes,
- Situation/environment (complexity, uncertainty, dynamics, and level of threat), and
- Response requirements (timing and precision).

Mismatches between these factors in the system design may result in the ineffective use of resources and, in the worst cases, disastrous system errors and failures. The consideration of these factors should be included in the systems engineering development process at each phase. Cognitive factors for C^2 decision support should be addressed during system requirements analysis to understand the relationship between the system functions and the operational, or purposeful, requirements. This can be accomplished by incorporating information about the users and tasks gleaned from organizational doctrine, direct observation, and other sources to answer questions such as those listed below.

- How do the decisions and tasks impact the mission? How critical are they? How rapidly must decisions be made? Where and how will it be disseminated?
- Will the decision maker have experienced a wide or narrow range of interpretation situations?
- Does the decision maker interpret this information routinely? Occasionally? Rarely?
- What situational contingencies might negatively affect the decision maker's accurate interpretation of critical information?
- What impacts will information "quality" (e.g., information completeness, accuracy, precision, timeliness)

have on the decision maker's performance?

- How does the change in one factor relate to the interpretation of another factor in the decision? How does the decision maker need to view the information to comprehend the meaning of the change?
- How often should the data be updated to support accurate situation assessment and provide timely feedback on actions taken?
- Does the decision maker ever need to know or review values of a specific factor going back several updates? If so, is the current direction of the system design implying that the decision maker will retain this in his/her memory or keep notes off-line?

These questions and others also guide the determination of measures of performance (MOPs) and effectiveness (MOEs) for iterative evaluation of the resulting designs and systems.

4. *Supporting Technology and Process Co-Evolution*

As technologists, our paradigm is often: build it, test it, and train them to use it. This paradigm fails when new technology effects dramatic changes in organizational process. Introducing advanced decision support technology into large, complex organizations via multiple, interdependent information systems demands an understanding of concurrent changes in technology requirements, in organizational processes, and in learning required to improve organizational capability. Human decision makers train to use evolving systems while discovering best applications of those systems in a changing environment and while providing feedback on emerging requirements to system developers. When these interdependent activities are not synchronized, organizations find that they have systems delivered and processes in place which solve last year's problems and fail to address current needs.

Each year DoD research and development funds a range of advanced C^2 technology efforts – yet even the best technical ideas often do not survive prototyping because they fail to adequately address operational users' needs. In recent years, the U.S. military adopted iterative development models that evolve system requirements through a series of prototypes and phased implementation. Iterative development is a discovery process that requires:

- Good systems engineering practices for analysis, design and evaluation;
- Innovative concepts of operation that focus technology application on decision makers' needs; and
- Effective methods for analyzing and incorporating feedback from users.

The first two factors are well-known, though not often well-executed; the third factor is problematic in developing C^2 decision support systems. No adequate methods exist to incorporate cognitive and organizational models into requirements analysis, design, or evaluation. As a result, advanced information technology often does not benefit operational users in a reasonable time frame – if at all.

4.1 Analysis & Evaluation in Co-Evolving Technology & Process

Gleick (1987) describes inquiry into the complex domains of nonlinear, dynamic systems as "walking through a maze whose walls rearrange themselves with every step you take." Patton (1990) relates Gleick's description of chaos theory to qualitative investigation of human systems, including the following requirements and implications:

- *Embracing chaos* - importance of observing, describing and valuing turbulence and disorder in complex, dynamic systems – rather than forcing a narrow, ordered view;
- *Examining small things* - studying the qualitative value of small things though they may lack quantitative significance;
- *Appreciating simplicity* - simple systems may generate complex effects;
- *Understanding the effects of investigation* - activity in nonlinear systems changes the definitions, thus participation in investigation and interaction with investigators can change the nature of a complex system permanently;
- *Coping with dynamics* - investigating constantly changing phenomena without imposing static structures; and
- *Developing interpretation* - meta-knowledge for evaluation of human systems is still evolving.

In their 1997 study on human-centered design, Winograd and Woods contend "new technology transforms what it means to carry out activities within a field of practice." It changes the task knowledge required and how knowledge is used in different situations. Introducing technology changes the roles of people within the overall decision system – changing their strategies and their patterns of collaboration to accomplish goals. These changes in organization process due to introduction of information technology are often difficult to understand. System evolution, usually software driven, compounds the problem for both the organization and observers. Automating manual, paper-based processes without redesigning those processes invariably limits the improvements and loads the existing process with additional labor requirements. Additionally, the organization can find that it has solved the wrong problem when it poorly projects the impacts of change. One of the most difficult aspects of rapid (or evolutionary) system development is managing the exponential explosion of system requirements. Although an evolutionary model presumes an iterative definition of requirements, fielding a suite of organizational support systems the magnitude of the Army's Force XXI "system of systems" introduces tremendous change into organizations and processes. The result is a co-evolution of systems and organizational processes that requires extraordinary effort from organizational leadership and systems engineers.

In rapid system development the analysis, design, implementation, evaluation cycles are almost continual. The principle motive behind these approaches is the need to field a system solution quickly in a situation where the requirements cannot be fully specified in advance; the evolution of the system is accomplished through iterative prototyping. Complex organizational environments usually require large-scale system solutions that are equally complex. Using rapid development techniques for designing large-scale systems involves considerable risk to both the developer and end-user organization. Barry Boehm's Spiral Development Model (Boehm, 1987) incorporates the iterative development approach with evaluation and risk assessment in each phase. To be successful, developers and stakeholders must agree on an initial, informal set of requirements, sketch a design to meet those requirements, implement a prototype, and evaluate the prototype against the requirements and design. Based upon this evaluation, both requirements and designs should be modified for the next prototype so that they evolve along with the prototype.

In iterative design and development processes, prototype evaluation aids in verifying and validating the working design against the requirements; but, rapid development is only successful when each prototyping phase culminates with some form of evaluation. Evaluation goals vary depending upon the current development phase. Early evaluation provides a means for extending requirements and task analyses to the evaluation of the procedures embedded in the current design solution. In this manner, evaluation provides a means for acquiring information about the current version of the system design with respect to the performance characteristics and capabilities of the human-computer cooperative decision system.

C^2 decision systems involve multiple stakeholders whose input both defines and supports the evolution of technology introduction, training and exploitation (Figure 2). Each party has evaluation needs that inform their decisions in developing new technology, technology application, and training. The framework for each evaluation phase must reflect the system requirements hypotheses that drove the design of the activity; feedback from evaluation is a course correction device. For example, early evaluation allows system design modification during the initial life cycle phases when the cost to modify is low. For the design team, evaluation is also a discovery process. Findings from the evaluation provide input for requirements and design modification and help to set measures of performance (MOPs) and measures of effectiveness (MOEs), benchmark targets for later system-level evaluations. Evaluation feedback informs not only the design of system functions and features, but also provides input for the design of related components. For the project manager, evaluation feedback is a critical part of project planning and control. Early evaluation flags potential problems that may require cost, schedule or, in some cases, contract modification. Evaluation also must inform the organization about the training requirements inherent in successful introduction and use of the technology adopted.

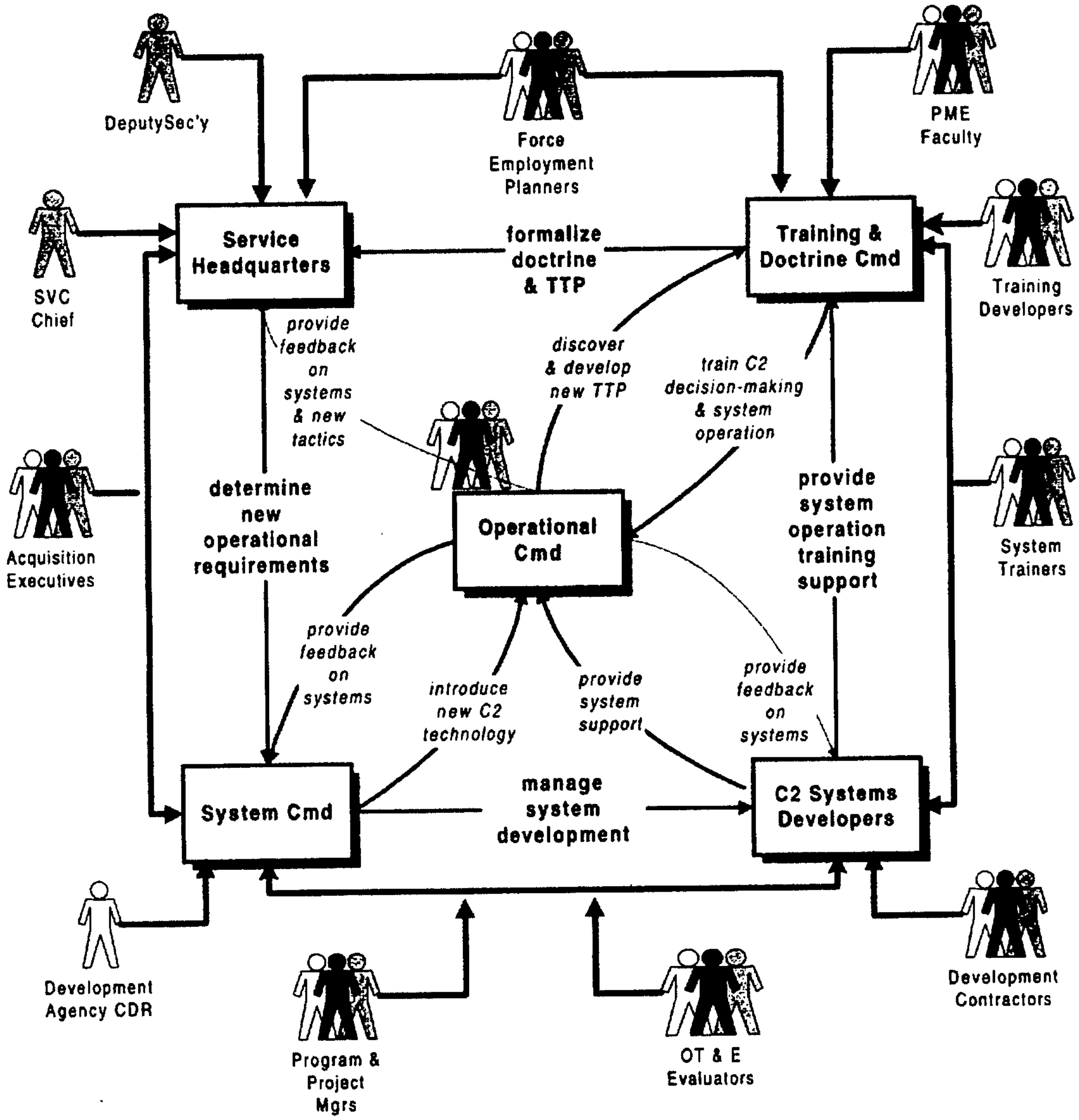

Figure 2: Stakeholders & Roles in Technology Enabled Change for C^2 Decision Systems

The introduction of new technology into a complex organizational system will modify its processes and the related structures and subtasks. This organizational evolution must also be mapped into the evolving system and development process. Defining cognitive requirements and evaluating their implementation in support systems is a critical part of ensuring the effectiveness of new systems. Decision-focused design embraces three basic principles:

- Design of C2 decision aids embodies the relationship of human users and computer-based aids in achieving organizational goals;
- Decomposition of decision functions, processes, and tasks provides measurable indicators of the extent to which specific designs fulfill system objectives; and
- Utility of evaluation to the system design process depends upon the application and interpretation of C2 decision making measures in the context of a valid framework of objectives, functions, processes, and tasks.

For all these reasons, the qualitative aspects of support to decision-making must be included in the earliest evaluations. Designs for the complex systems supporting C^2 decision making derive conceptual requirements from models of C^2 processes. The doctrine incorporated in these models and the missions defined by the organization provide the context for identifying the functional and task requirements that structure the relationships of humans

and machines. These requirements, in turn, help to determine the appropriate measures of performance (MOPs) and measures of effectiveness (MOEs) that form the selection criteria for decision aiding designs. These can be applied through a combination of checklists, expert reviews, end-user walkthroughs, and heuristic evaluation. As early as possible, developers need the input of "real users" using the system under the most representative conditions. Warfighting exercises and experiments generate a wealth of information on the complex interactions of users, processes, and system supports that can be used to assess the development paths of future systems.

4.2 Role of Training & Education in Process Innovation & Technology Development

4.2.1 Capturing Knowledge from Discovery Learning

Training designs with the new systems often portray the military force's organizational processes – encompassing tactics, techniques, and procedures – as known and standard. Introducing new information technology requires discovery-based learning and experimentation, both at the individual level (i.e., how does this system perform and how can it help me?) and at the organizational level (i.e. how can this technology help us achieve missions?). Organizations must experiment with the systems in order to discover their performance characteristics, discover how they affect organizational process, and use their experimental results to invent new TTP. Since decision support systems affect cognitive and decision-making processes, understanding the organizational effects is not easy and makes discovery and invention more complex. The knowledge discovered in training and educational exercises is invaluable to the iterative development of the systems, the evolution of the operational processes, and – ultimately – to the successful integration of new technology into the larger C^2 decision system.

Operational combat teams use training events – both simulated staff exercises and tactical field exercises – to experiment with an extended range of operational issues. To foster the positive benefits of discovery learning, certain aspects of these training events must not be scrutinized as though they represent well-established practices. Instead, evaluation metrics must focus on capturing the substance of innovations and tracking the findings so that important learning is not lost to the organization or other organizations which could benefit from innovation and experience.

When organizations introduce new technology into their decision system, it is important to distinguish the initial purposes of training and education from those of future training once the tactics, techniques and procedures (TTP) are well-established. During initial phases, the units are training with and using technology that is still evolving and for which the TTPs are evolving. Thus, their exercises serve not only to train commanders, staffs and soldiers, but also to explore application of these new capabilities. Rather than coached repetition of time-tested TTP to drill towards established performance criteria (i.e., repeated practice to mastery), the training events serve multiple functions. Naturally, these events exercise staffs and soldiers in basic skills required to use the new technology. In addition, the training events allow the commanders and their staffs and subordinate units to try out new procedures and tactics in simulation and in the field. Examining these events as against standards for established practice invites an inappropriate evaluation of the resulting performance. In fact, the evaluators themselves are in a discovery mode, trying to evolve meaningful measures for the evolving organizational processes.

Methods developed to study teams within organizations afford some useful approaches for evaluating evolving organizations. For example, McGrath (1984) presents a conceptual framework for studying groups in terms of the impacts and interdependencies of:

- Interactions between and among group members;
- Characteristics of individual group members;
- Tasks performed; and
- Physical, socio-cultural, and technological properties of the task environment.

McGrath's group task typology synthesizes the theoretical work of several social scientists to classify group activities in four processes: generating, choosing, negotiating, and executing. McGrath's model reveals perspectives relating the processes and their task subtypes to consider the group interaction (conflict vs. cooperation) and the associated activities (conceptual vs. behavioral). Applying these perspectives to command and control allows us to view execution tasks as the synchronized tasks performed by a combat team and its allied units (cooperation) to effect defeat upon a common enemy (conflict).

Finally, it is a different matter to set organizational performance standards or design training models that feature

organizational adaptability as a desired performance attribute. "Agile" or adaptive organizations, in the sense of possessing effective processes for capitalizing on discovery and invention, are desirable, but measurement issues are non-trivial, not to mention the problem of establishing performance standards. While there has been considerable work in the process change and business process re-engineering metrics in the corporate world, those metrics are not necessarily appropriate for the combat units. MOPs and MOEs for evolving combat organizations and need more comprehensive consideration.

4.2.2 Using Exercise Evaluation for Feedback & Control

While field exercises most closely resemble the operational target environments, operational combat units are not the place to do systematic or "scientific" discovery. Operational combat units are severely time-constrained; commanders are looking for the first cut at good ideas. They do not have the opportunity to spend extended time exploring the possibilities of new technologies or trace down the doctrinal/tactical implications of the new TTP they develop.

A number of factors combine to hinder effective collaboration between the combat units, training command, system development command, and the development contractors, including:

- Constraints on time available in the training schedule for interaction;
- Problems communicating research goals and methods to commanders and staff;
- Non-interference requirements when observing decision-making;
- Commanders and staff viewing the observers as evaluators, or graders, rather than collaborators.

An ideal goal is to establish a partnership, very early, between observers and the organization. As the organization begins technology introduction, the observation team can witness and record the discovery and innovation as it occurs for use by operational planners. For example, when a combat unit tries a technique to extend their battlefield sector coverage, a whole substructure of interesting ramifications develops. Doctrine and tactical wisdom says dispersion is good for survivability; yet regrouping for massing fires is also essential. So, the operational command might develop additional procedures for hand-off of scouted targets to the forward elements of the battalion to ensure the brigade can focus forward and not lose their battlefield awareness. In doing this, they will uncover some intelligence gaps they believe will be filled with upper echelon intelligence products – but they can not pursue those issues. Moreover, TTP that work well for one commander may not work well for another – we need to understand what is common and what is unique. Doctrine and training thinkers must identify and track this thread; they may develop systematic scenarios to explore the ramifications and work these issues into future exercises to complete the work begun at the operational commands. This has long been the job of the Army doctrinal thinkers – it is not new for information technology, but there is tendency toward more rapid adoption and the TTP may be so embedded into systems and training that it will be difficult to adapt them for different purposes.

We have observed active combat units as they have used training activities to explore new tactics, techniques, and procedures. Two specific problems appear to limit efficient use of training time: inadequate conceptual models of system operation and the lack of "starter" heuristics or baseline rules to provide an initial "strawman" process. At the end of exercise segments, technical "hot washes" and operational after-action reviews (AARs) provide a forum for learning. The AARs that we observed focused on linking process with outcomes; learning occurs when commanders and staff can establish how and why the battlefield operating systems and functions contributed to performance. Most of the conventional AAR support information remains limited to outcome measures of performance, such as targets destroyed, resources used and attrition on both sides. The Army is evaluating several AAR support tools that capture information from simulation-based training exercises, but these tools do not directly support organizational process (TTP) evaluation and feedback beyond "outcome counts."

In contrast to the operational constraints on combat units, the Army professional schools provide a low-risk – albeit less realistic – environment to explore the capabilities of new C^2 information systems. Exercises and experiments at the U.S. Army Command and General Staff College (CGSC) and Battle Command Battle Lab (BCBL), Ft. Leavenworth engage mid-career officers as role players in C^2 scenarios. The students' use of cognitive support provided by the Army Battle Command (ABCS) systems mirrored some behaviors observed at large-scale exercises. These similarities suggest not only general patterns of use, but also the potential value of the professional education environments as "laboratory" settings for discovery learning in the introduction and use of advanced information technology in command and control processes. Officers in the school laboratories can risk making mistakes during discovery without out detriment to their careers. This advantage is somewhat offset by the fact that many of the

participants will role-play command positions above their grade and beyond their experience. To be effective, schoolhouse experimentation must include sufficient participant preparation to ensure the best possible fidelity. Table 1 compares the benefits and limitations of exercises conducted in classroom, simulated, and field settings.

Setting	Description	Benefits & Limitations
Classroom	Individuals and teams (a command staff or staff element) learn about system features, functions in a controlled classroom environment. The system probably is not coupled with other systems. Organizations assess individuals and team learning.	• Limited opportunity for participants and teams to learn performance characteristics in sterile environment • Limited opportunity for participants to invent new techniques and procedures • Difficult to experience tactical impacts of system use • Most desirable setting to learn system features and functions • Invention of new TTP problematic because of low environmental fidelity, absence of interdependent systems
Simulation Exercise	Individuals and teams use the system in a simulation-based environment to practice mission execution or discover system application to mission execution. Participants learn about possible tactical implications of system. The system may be coupled with other systems. Organizations assess tactical impact and impact on TTP.	• Not a desirable setting for discovery learning of features and functions • Opportunity for participants to learn performance characteristics, assuming "valid" simulation environment and performance of other systems • Participants may experience some of the tactical impacts of system use • Opportunity to discover impacts on team processes and invent new team TTP • Opportunity for organization to discover tactical implications and performance depends on presence of other systems and simulation environment – including simulation effect on other systems / fidelity. • Organizations may experiment with techniques and procedures to discover best application of system.
Field Exercise	Individuals and teams use the system in field exercise to practice mission execution. The system may be coupled with other systems Participants learn about possible tactical implications of system. Participants discover system performance characteristics and effects of different techniques and procedures. Organizations use the system to practice planning and mission execution in a field setting.	• Participants experience some of the tactical impacts of system use • Not desirable for individual discovery based learning of features and functions • Opportunity for participants to learn performance characteristics, assuming valid performance of other systems • Environment most closely matches real world operations; best opportunity for inventing and evaluating impact of systems on team TTP • Best opportunity for organization to discover tactical implications and performance characteristics of new system • High costs for conducting experimentation to drive discovery and invention of formal TTP

Table 1: Evaluation Issues for System Use in Operational Environments

Simulation-based training exercises furnish a low-risk, medium-fidelity environment for both user and organizational learning. Typically, data capture and analyses focus on basic battle outcome metrics for use in AARs. Outcome measures alone are not sufficient to understand the decision process impacts of new technologies or inform their continued development and integration. CSE champions the concept of holistically designing the decision system to support the collaboration of individuals and computer-based information systems within a larger organizational process to solve problems. CSE methods incorporate qualitative and quantitative analysis of both the content and the process of decision making in a team or organization. The techniques employ and integrate a variety of model types (i.e., flows, processes, control structures, and functional relationships) to relate the human decision makers, information systems, organizational structures, and environmental context. Cognitive and decision process

analysis methods provide the means to achieve the synergy between what is learned in operational field exercises and what analysts can investigate in greater detail in other settings.

Users' concepts of system capabilities and quality affects not only their ability to exploit the system for operational objectives, but also their ability to imagine new ways to combine systems to achieve operational objectives. For this reason, the fidelity of the training environment is critical. For example, technical difficulties during pre-exercise training may lead students to believe the intelligence information provided by one system significantly lags behind system updates. As a result, they may "learn" to compensate by using a less effective method for updating their operational intelligence. An AAR tool that only provides the outcome measures of mission effectiveness would not help uncover the reason for the differences in performance. In order to uncover this issue, the officers conducting the AAR needed information about the team processes that drove operational decisions. This information can be drawn from simulation message traces, system messaging, and observation. Analysis would map the decision making team members, the information they used and its sources to the outcome effectiveness of the mission. We are working now to determine requirements and develop automated methods for capturing and analyzing this information to support rapid feedback in exercise AARs.

5. *Future Research & Development*

Advances in simulation environments and AAR support present opportunities to provide robust feedback on technology-supported decision making processes, as well as the combat effectiveness of those decisions. To realize these possibilities, research and development efforts must focus on innovative methods to capture decision process and use analysis of relationships between decision-making process and technology to support system design evolution. For example, what are effective ways to represent and understand process control in a simulated environment with autonomous entities? How do we select the right concept and simulation abstraction for training future decision makers?

This paper presents a conceptual model of a C^2 decision system that comprises the command and control organizational functions, tasks, and processes. This metamodel integrates multiple models, including user profiles, decision and functional task models, organizational models (goal hierarchies, control structures, processes, and functions), hardware, software and communication architectures, information models (data structures, and information flow), human-computer interaction models (information presentation and interaction models, and collaboration models).

Throughout this paper, we discussed the factors that determine the effectiveness of information technology in supporting the C^2 decision system in situation assessment, COA evaluation and selection, and the synchronization of execution. System developers must support decision process capture and analysis to help organizations learn – through discovery-based learning or in training via execution practice. The conceptual model for training and exercise support systems should include an AAR process model that incorporates the instructional objectives and subsequent cognitive requirements in order to drive technology requirements. The complex interactions between the human, machine, and communication components that define C^2 decision systems require the synthesis of multiple model types. Our next steps will look at how simulations and the conceptual models that link simulations to C^2 decision support systems may best support the multiple goals of system development, organizational process evolution, and discovery learning. The goal of this research is the design of a sufficiently robust framework to guide construction of models that will the exploration and evolution of C2 systems, including:

- Analyses of requirements (system objectives, functions, tasks, operational capabilities);
- Evaluations of performance and effectiveness characteristics (current and potential);
- Exploration of the impacts of new technology on organizational processes; and
- Indications of the training and education required to achieve desired results.

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Major Challenges Posed by Future C2 Assessments

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A. Abstract

This paper looks ten years into the future to identify and characterize the major challenges that assessors of Command and Control (C2) will have to confront. As a context for that assessment, a trend analysis is performed of the factors that are perceived to have the greatest impact on future C2 assessment needs. Using a variant of the framework developed in the NATO Code of Best Practice (COBP) for C2 Assessment, the results of the trend analysis are aggregated to identify and characterize major challenges posed by future C2 assessments.

B. Introduction

During the last decade, there has been renewed interest in the problem of evaluating the impact of C3I on mission effectiveness. To establish a baseline, Panel 7 of the NATO Defence Research Group formed an Ad Hoc Working Group on the Impact of C3I on the Battlefield in 1991. That working group was requested to assess the state of the art in C2 analysis [NATO AD HOC WORKING GROUP]. Based on the recommendations of the Ad Hoc Working Group, Panel 7 constituted a Research Study Group-19 (RSG-19) (subsequently redesignated Studies, Analysis, and Simulations (SAS) - 002) to develop a Code of Best Practice (COBP) for Assessing C2. The results of those deliberations have recently been published and are the focus of this Symposium. They are limited, however, to the issue of assessing C2 in the context of a limited set of conventional warfare missions.

To establish a foundation for follow-on activities in this area, this paper looks ten years into the future to identify and characterize the major challenges that assessors of C2 will have to confront. As a context for that assessment, a trend analysis is performed of the factors that are perceived to have the greatest impact on future C2 assessment needs. Using a variant of the framework developed in the NATO COBP for C2 Assessment, the results of the trend analysis are aggregated to identify and characterize major challenges posed by future C2 assessments.

C. Trend Analysis

Figure 1 identifies the major factors that will drive C2 assessment needs over the next decade. These factors include evolving threats, the strategy that is being developed to respond to those threats, the operational concepts that are being developed to implement those strategies, the institutional activities that are underway to formulate and evaluate

those operational concepts, the systems that are emerging to support those operational concepts, and the acquisition process that is being considered to develop and field those systems. The following discussion identifies emerging trends for each of these factors and infers resulting C2 assessment needs.

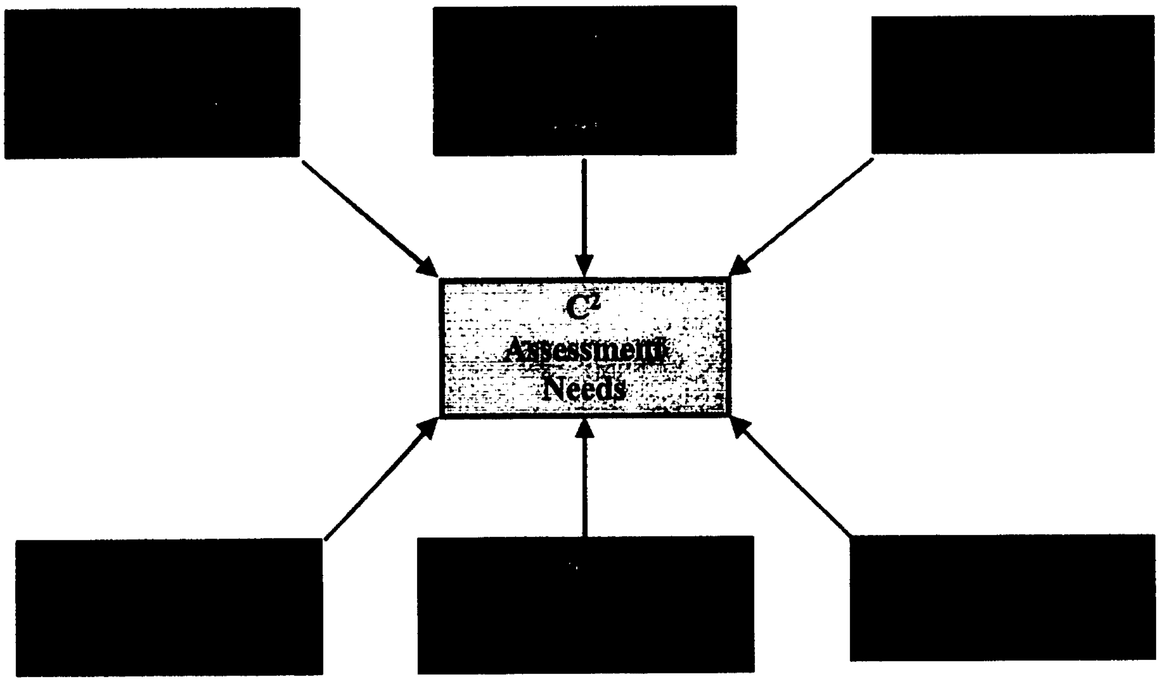

Figure 1. Trends That Are Driving C2 Assessment Needs

• **Threats.** Over the next decade, a substantial change in the threat spectrum is envisioned. First, in the area of conventional conflict, a move towards more asymmetrical conflict is anticipated. This projection is based on the sense that future adversaries will lack the resources to match the sophisticated C2-weapons system mixes of the West. To counter that disadvantage, potential adversaries are developing anti-access capabilities (e.g., more precise ballistic and cruise missiles; weapons of mass destruction) and appear to be exploring the doctrine and concepts of information operations. To deal with those threats, new assessment tools are needed that are appropriate for such asymmetric operations. A discussion of the ability of selected existing simulations to deal with C2 and Information Warfare (IW) for conventional warfare is provided in one of the other papers presented in this session [STEVENS, ET AL].

Of even greater potential impact to the C2 assessment community, is the emergence of a full set of New World Disorder missions. These include, *inter alia,* humanitarian assistance, disaster relief, peacekeeping, peacemaking, counter-terrorism, and critical infrastructure protection. In general, these missions can be characterized as complex, poorly defined problems, which we are currently ill-equipped to address. They will involve novel organizational relationships, demand the generation of new scenarios and

meaningful measures of merit, and call for databases and assessment tools which do not presently exist.

It is perceived that there are fundamental differences between the C2 assessment problems posed by future conventional warfare and New World Disorder missions. Those differences, and their implications, are identified and discussed in the next section.

• **Strategy.** To respond to these emerging threats, a strategy is emerging that is often referred to as the Revolution in Military Affairs (RMA). There are two major distinguishing characteristics of the current formulation of the RMA. First, it hypothesizes that fundamental advantage accrues to the side that possesses information dominance (i.e., the ability to perceive the battlespace in a complete, accurate, timely way, while denying that capability to your adversary). Preliminary assessments have been published recently, using game theoretic arguments, that tend to support that hypothesis [BRACKEN & DARILEK]. However, a much more extensive set of tools and analyses is needed to fully validate and quantify this assertion.

Second, advocates of the RMA note that it is not simply a matter of acquiring new technology. It is critical to develop and implement new doctrine, concepts of operations, tactics, techniques, and procedures (TTPs), and training to exploit fully the advantages implicit in new technology. This ability to create an effective self-consistent set of systems, concepts, and training has been referred to as "co-evolution" [EHRHART & BIGBEE]. This raises the need to develop the methodologies and tools that are able to assess fundamental, simultaneous changes in many dimensions of the problem.

• **Operations.** Several operational concepts are emerging to implement RMA strategies. One prominent example is "Reach Back" operations which envisions a small "footprint" in the immediate theater with extensive support from assets in sanctuary. One objective of this operational concept is to counter the anti-access capabilities which potential adversaries are developing. These emerging concepts make significant demands on the part of the C2 assessment community. First, tools are required to help formulate and assess the effectiveness of the C2 associated with these concepts. Second, it is envisioned that C2 analysts would be part of the resources in sanctuary that could be supporting the operational user with near real time assessments of options. Both of these roles will require the development and application of novel databases and tools.

• **Institutional Initiatives.** Within the US, a number of institutional initiatives are underway to formulate and evaluate these emerging operational concepts. One set of these initiatives falls under the category of Advanced Warfighting Experiments (AWEs). As an illustration of these AWEs, the Reach Back concept is being explored in a variety of conventional conflict scenarios by the US Services (e.g., Hunter Warrior by the US Marine Corps; Expeditionary Force Experiment (EFX) by the US Air Force). It is recognized, however, that to be truly meaningful, these innovative operations have to be assessed in the context of joint and coalition missions. To do so will require the development of an orchestrated mix of tools to help plan, execute, and exploit these

AWEs. As an initial step, assessors are pursuing the "model-test-model" paradigm. However, to implement that paradigm effectively it will require the development of databases and tools that are flexible enough to support the joint and combined evaluation of new combinations of systems, concepts, and training. Initial steps are being taken to generate a federate of such tools in the Trailblazer program (using the recently developed High Level Architecture (HLA) to federate three independently developed simulations), but these efforts are still in their infancy.

• **Systems.** Through a set of recent initiatives, new systems and architectures are emerging to support these emerging concepts. One such initiative envisions the C2 system as an integrated "platform" that provides an infrastructure upon which many applications can ride. One manifestation of this concept is the US Global Command and Control System (GCCS). Since this aggregated system supports multiple missions, it poses a problem for the C2 assessor in the structuring and decomposing of the problem. A second major trend is to view the C2 system as a "system of systems" (and multiple systems of systems, perhaps arising from coalition operations, as "federations of systems"). A challenge for the C2 assessor is to identify and help correct any interoperability issues that may limit the effective operation of such complex mixes of C2 and weapons systems. The C2 assessment community will have to develop new measures of merit and tools to support the iterative evolution of these capabilities.

• **Acquisition.** New approaches are being proposed to develop and field these complex C2 systems and systems of systems. One of these approaches involves the consistent development and application of models and simulations throughout the lifetime of a system and the sharing of these tools (and related data) throughout the community. Pilot efforts to implement this concept are being pursued under the rubric of Simulation Based Acquisition (SBA) [HUGHES]. It is widely recognized, however, that such a fundamental change will require a basic cultural change in associated institutions, tools, and processes.

D. Comparison Between Conventional War and New World Disorder Missions

As noted above, there are substantial differences between the C2 assessment problems posed by future conventional warfare and New World Disorder missions. These differences are highlighted in Table 1 and discussed below.

Category	Factor	Conventional Warfare	New World Disorder Missions
Mission	Focus	Military adversary	Uncertain (e.g., hacker to nation state)
	Understanding, commitment	Common (military)	Uncertain (political-social-military)
Inform-ation	Nature of the problem	Known unknowns	Unknown unknowns
	Key Question	How to get information	What information to get
	Focus	Enemy military	Military-political-economic-social factors
	Situation Awareness	Common operational picture (air-land-sea)	Unclear what should be monitored
	Databases	Very large, well structured	Larger, less structured

Table 1. Comparing Conventional Warfare and New World Disorder Missions

In conventional warfare, the mission tends to be relatively stable, there is a clear focus on a well-defined enemy, and the military participants have a common understanding and commitment. Conversely, in New World Disorder activities, the mission may be relatively dynamic, it is often highly uncertain as to who is the enemy (or, in fact, if there is an adversary), and the heterogeneous participants (frequently consisting of coalition partners and Non-Governmental Organizations (NGOs)) will rarely have a common understanding of the problem or completely coincident interests.

The differences between conventional warfare and New World Disorder missions are also evident in their information needs and focus. In conventional warfare, the issue of information gathering and management focuses on the issue of "known unknowns" (e.g., where are the enemy's divisions?). For that case, the key question is *how* to get the needed information (e.g., What are the key signatures for the targets in question? What sensors should we task to exploit those signatures?). Clearly, the focus is on the enemy military and one objective is to assemble a complete, timely, and accurate common picture of the air-land-sea-space situation. The result is a very large, time sensitive data base, but one that is relatively well structured (e.g., organized around the enemy order of battle).

Conversely, in the New World Disorder missions, the problem of information gathering and management is dominated by "unknown unknowns." Thus, the primary question to address is *what* information to get. The information focus is much more diffused because of the myriad of economic, political, social, military, and legal factors that must be considered. Consequently, situation awareness is much more complex and it is less clear

what should be monitored. The resulting data bases are likely to be much larger than their military counterparts and less structured.

E. Major Challenges Posed by Emerging Trends

In the NATO COBP for C2 Assessment, a general, iterative process was introduced. Figure 2 highlights the major steps that should be performed in the assessment. The figure has been augmented to emphasize that the process must be understood within the context of the people who must participate in the process (e.g., the decisionmaker, C2 analyst, tool maker) and the cultural setting within which the process is conducted.

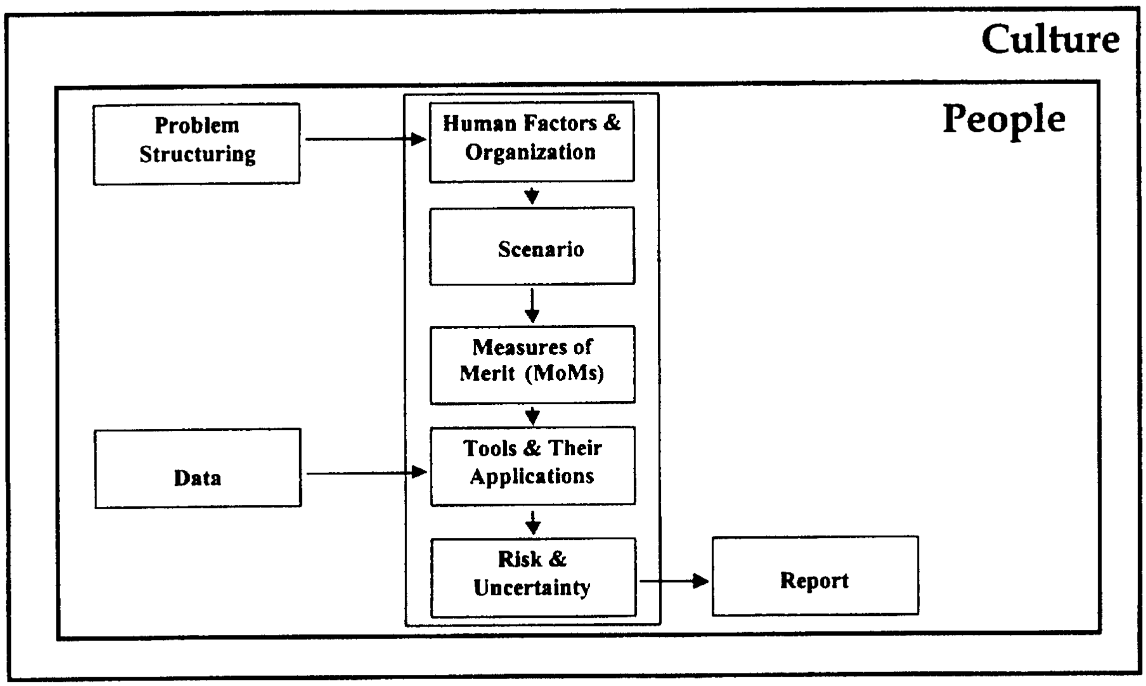

Figure 2 Framework for Identifying Major C2 Assessment Challenges

Using this framework, a qualitative analysis was made of the major challenges that the C2 community must confront as it attempts to deal with emerging trends.

• **Problem Formulation.** Extreme care must be taken in *structuring and decomposing* the problem. In most C2 assessments, it is extremely difficult to subdivide the problem into manageable segments that can be analyzed substantively, the results of which are amenable to meaningful synthesis to shed light on the original, larger problem. Historically, a mission-oriented decomposition proved to be an effective approach for dealing with this issue [SIGNORI & STARR]. However, trends in conventional conflict suggest that it may be less successful in the future. That is because modern warfare has stressed the greater integration of heretofore loosely coupled missions (e.g., air-land-sea-space conflict). In addition, as noted above, there is a trend towards developing a

common C2 infrastructure that supports many, if not all, mission areas. This makes it less useful to decompose the conventional C2 assessment problem along mission lines.

From a New World Disorder perspective, the issues associated with problem formulation are still more daunting. There is a broad spectrum of operations that fall within this rubric (e.g., humanitarian assistance, peacekeeping, peacemaking, critical infrastructure protection) which involve political, social, and economic dimensions that have been historically outside the scope of C2 assessment. The formulation of the problem is further confounded by the fact that they involve non-traditional stakeholders (e.g., NGOs; owners and operators of critical infrastructures) who must be included in the assessment.

• **Human Factors and Organizational Issues.** A primary challenge arises from the fact that C2 deals with *distributed teams of humans operating under stress*. Historically, C2 assessments of conventional warfare have had particular difficulties in treating cognitive processes and performance modulators (e.g., factors such as morale, fear, and fatigue).

Looking to future, a new set of challenges emerge. As noted above, it is anticipated that changes to C2 systems will often require "co-evolution" (i.e., coincident changes in tactics, techniques, and procedures (TTPs), doctrine, or related factors), which must be considered in the assessment. In addition, it is hypothesized that the future C2 system will have the property of being "self-adaptive/self-organizing" [EHRHART & BIGBEE]. These concepts are very difficult to conceptualize and assess and are the subject of ongoing research efforts.

• **Scenarios.** The NATO COBP concludes that it is necessary to perform assessments on the effectiveness of C2 in the context of an appropriate scenario. The scenario framework subsumes three major categories: external factors (e.g., political/military/cultural situation), capabilities of actors (e.g., friendly forces, adversary forces, and non-combatants), and environment (e.g., geography, terrain). The challenge is to explore the scenario space rapidly and to focus the assessment on the "interesting" (e.g., critical, stressing) regions of scenario space. The COBP cautions that, due to the complexity of the C2 arena, *limiting attention to a single scenario is almost always an error.* The challenge to the community is to develop scenario tools that can be used to generate scenarios rapidly and efficiently and to identify critical, stressing segments of scenario space. The challenge will be greatest in developing scenario generation and exploration tools that are germane to New World Disorder missions.

• **Measures of Merit (MoMs).** The NATO COBP states that *no single measure exists that satisfactorily allows the assessment of either the overall effectiveness of C2 or the performance of C2 systems.* Drawing on the work of prior Military Operation Research Society (MORS) workshops [SWEET, ET AL; PAWLOWSKI, ET AL], a multilevel hierarchy of MoMs was recommended. Four levels of the hierarchy are envisioned (although additional levels can be added to respond to the specific nature of the problem):
- Measures of Force Effectiveness (MoFE), which characterize how a force performs its mission (e.g., loss exchange ratios);

- Measures of C2 Effectiveness (MoE), which characterize the impact of C2 systems within the operational context (e.g., ability to generate a complete, accurate, timely common operational picture of the battlespace);
- Measures of C2 System Performance (MoP), which characterize the performance of internal system structure, characteristics, and behavior (e.g., timeliness or accuracy); and
- Dimensional Parameters (DP), which measure the properties or characteristics inherent in the C2 system itself (e.g., bandwidth).

The C2 community has had great difficulty in standardizing on a generally accepted set of measures at each of these levels and in establishing the relationships between and among MoMs at different levels of the hierarchy. The greatest challenge, however, will be to extend this hierarchy to include "measures of policy effectiveness" to characterize New World Disorder missions. For example, recent efforts to analyze the effectiveness of peacekeeping missions in the Balkans have introduced a broad mix of policy effectiveness measures (e.g., socially, the number of playgrounds on which children are playing soccer; politically, the ability to conduct fair elections; economically, a variety of measures characterizing the change in economic well-being). It remains to be demonstrated whether credible C2 assessments are feasible that can express the impact of C2 on these measures of policy effectiveness.

• **Data.** A decade ago, at a MORS Workshop on Simulation Technology 1997 (SIMTECH 97), Dr. Walt LaBerge gave a presentation entitled "Without Data We Are Nothing." [BRADY]. That talk underscored the importance of data as the engine for creating key tools and for performing assessments. Unfortunately, the C2 assessment community has major shortfalls in its ability to acquire, verify, validate, and certify (VV&C), transform, store, or make accessible key data. The challenge is greatest for New World Disorder missions where the required databases are generally extremely large, poorly structured, and sparsely populated prior to the mission.

• **Tools and Their Application.** Historically, the C2 assessment community has tended to focus on constructive models and simulations (M&S) as its preferred assessment tool. However, there is a much broader set of potential tools including, *inter alia,* expert elicitation; analysis; constructive, virtual, and live M&S; and the results of actual operations. Typically, there is an increase in resources and lead time as one moves across this tool set, with a corresponding increase in credibility.

The NATO COBP concluded that no single assessment technique is likely to be sufficient for many of the C2 issues of interest. This suggests the need to formulate and implement a strategy that selects and orchestrates *a mix of techniques* consistent with the nature of the issues and key constraints (e.g., resources, lead time). Due to the increased interest in concepts like "information superiority" and "information dominance", it is particularly important to have tools that represent adequately both friendly and adversary information processes. In addition, it is necessary to be disciplined in applying these tools. This suggests the desirability of employing formal experimental design matrices to govern the application of the tools and to support the generation of appropriate response surfaces

[STARRa]. Frequently, it is advantageous to identify "interesting" segments of solutio space, with respect to the issues at hand, by using very fast running tools (e.g., systems dynamics models) as a prefiltering mechanism. Once those "interesting" segments of solution space are identified, it is often appropriate to do more focused, in-depth assessments using more fine-grained tools (e.g., virtual M&S).

Of course, it is always highly desirable to use tools that have formally undergone verification, validation, and accreditation (VV&A). However, it is recognized that there are relatively few tools that have undergone such stringent quality control processes. To a limited extent, one can gain some confidence in the results if it can be demonstrated that independent assessments, drawing on the mix of techniques, can give rise to self consistent findings.

Overall, the major challenge to the community is to develop and implement a credible analytical methodology for addressing complex, poorly defined problems. Initial steps have been taken towards those ends (e.g., drawing on an orchestrated mix of "soft" and "hard" operations research techniques to address information operations issues [RICHARDSON]); however, an enormous number of challenges remain to be addressed before a complete, credible set of appropriate tools are available to the C2 assessor.

• **Risk and Uncertainty Assessment.** The NATO COBP notes that sensitivity analysis and risk assessment in C2 analyses have often been less than thorough because of the complexity of the issues being examined and limitations in time and resources. This is generally a mistake. *The need for, and results of, sensitivity analyses should be stressed in discussions with the decision maker.* The major challenge is to educate all stakeholders (e.g., decisionmakers, C2 assessors) on the importance of this process and to train individuals on appropriate ways to do it effectively and efficiently.

• **Report.** There is a disturbing trend in C2 assessment that frequently results in products in the form of briefings (generally without annotation). This poses a number of problems. First, there is often insufficient detail available to permit meaningful peer review of the product. Second, these products are generally poorly archived, making it very difficult to identify and access them. Thus, the community is being deprived of the intellectual reservoir that it requires to nurture future C2 assessments. The challenge is to encourage the generation of more complete products that are peer reviewed and made more broadly accessible to the community.

• **Iterative Approach.** The nature of C2 problems is such, that it is highly unlikely that meaningful results can be derived in a single pass through the assessment process. Thus, it is recommended that an *iterative approach* be taken. The initial cut should be broad and shallow to identify the issues of interest and the relevant segments of scenario space. Subsequent iterations would be progressively narrower and deeper (drawing on suitable tools) to gain progressively more insight into the major questions of interest. Relatively few C2 analysts manifest this discipline and structure in their work. The challenge is to make this approach the norm for the C2 assessment community.

• **People.** Historically, there has been inadequate attention paid to the problem of educating and training all the stakeholders in the C2 assessment process. A more systematic program is needed to respond to key emerging challenges. First, such a program should serve to support communications among all of the participants in the process (e.g., the C2 assessor about the decisionmakers' issues, constraints, and preferre ways to visualize the results of C2 assessments; the decisionmakers about the capabilitie and limitations of the C2 assessment community to perform such analyses). Second, the nature of New World Disorder problems is such that it requires a considerable expansion of the domain knowledge of the C2 assessor. For example, many such issues will require in-depth knowledge of social, political, and economic issues. Finally, it is not sufficient to merely publish a COBP for C2 assessment. Steps must be taken to train young analyst on the precepts of the code and to teach them how to use the evolving tool chest properly

• **Culture.** The framework for this paper placed the assessment in the context of the cultural setting within which the C2 assessment process is conducted (see Figure 2). This cultural context constitutes the greatest challenge that the community confronts if it is to be responsive to the issues of the next decade. To meet that challenge, it is asserted that *major* cultural challenges are required in three dimensions: institutional, assessment tool and the assessment process.

Institutionally, the current assessment culture is characterized by stovepiped organizations, outcomes that advocate protected positions, and reviews that are bureaucratic in nature. If the community is to be able to respond to emerging challenges, it must be transformed into one that is characterized by collaborative organizations, outcomes that are open and unbiased, and reviews that are conducted by subject matter experts.

Currently, assessment tools are oriented towards "Cold War" M&S, many of which are opaque to the decisionmaker. There is often pressure to limit the assessment to data which are institutionally "validated". The challenges posed by the New World Disorder calls for a much broader set of orchestrated tools (drawing on the resources of both "soft" and "hard" operations research) which are more transparent to the decisionmaker In addition, the uncertainties characterizing the problems call for the consideration of a broader range of plausible data.

Finally, the current assessment process tends to be characterized by attempts to suppress uncertainty and limit scenarios to a few, "blessed" examples. Analyses typically focus o symmetrical, force-on-force issues, that are artificially narrow in scope, with limited trade-offs conducted. A major change is required to the process to illuminate uncertainty and broaden scenarios to the "interesting" segments of scenario space. Future assessments must be able to treat asymmetrical forces in the context of the appropriate social-political-economic environment. The scope of the efforts must be broad enough t consider the full spectrum of C2, operational concepts, doctrine, tactics, equipment, and their interactions (i.e., "co-evolution"), with the full range of trade-offs conducted.

The magnitude of this challenge can not be understated. It will require visionary leadership in the community to initiate and sustain these cultural changes.

F. Summary

Colloquially, the major challenges posed by future C2 assessments can be characterized by "news" that runs the gamut from good to bad to worse to better.

The good news is that the community is beginning to understand a great deal more abou the C2 assessment problem. The assessment community is starting to recognize the importance of C2 in the context of the many missions that the military must perform; the practices that should be followed to perform credible C2 analyses; ... and what we don't yet understand!

The bad news is that currently, we generally do not do a satisfying job in performing C2 analyses. Although there are significant counter-examples to this statement [see, for example, selected papers in the Proceedings of the Fourth International C2 R&T Symposium], it is recognized that most studies of conventional conflict fail to live up to the COBP generated by NATO's SAS Panel-002.

The worse news is that the C2 assessment problem is getting substantially more difficult. The C2 assessment community is confronted with a host of New World Disorder missions and issues for which it lacks the key elements of effective C2 analyses (particularly relevant data and tools). In addition, these issues are in a constant state of flux, making it difficult to get traction on the problem. One of the most dramatic examples of this challenge is the Critical Infrastructure Protection problem, where the infrastructures and the threats to them are changing dramatically [STARRb].

Although these are daunting challenges, there is some better news. There is growing recognition of the importance of the problem, an appreciation of its complexity, and the commitment to address these problems. One of the manifestations of that commitment is the formation of the NATO Exploratory Team (SAS-E05). Over the course of the coming year, it should serve to determine the Way Ahead for the evolution of the NATO C2 Analysis COBP. It is left to that body to address and explore many of the challenges that have been identified in this paper. These include, *inter alia*, the challenges posed by the need for cultural change/leadership; extended, relevant MoMs; improved management of data; expanded tool chests (supported by needed R&D); accessible, peer-reviewed products; and attention to people skills and training.

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The Way Ahead

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INTRODUCTION

I am very pleased to have this opportunity to address this symposium and reflect upon the challenges we, in the research and analytical community, face at this critical junction in the evolution of military concepts and capabilities. The richness and diversity of the papers presented at this symposium are testimony to the strength of the national technical expertise present in NATO. All of us owe a debt of gratitude to those who participated in SAS-015 for their efforts to organize this symposium. We have come together to improve our knowledge of the state of the art and I for one have not been disappointed. I will return to my country and my job enriched and invigorated by the ideas presented and discussed here.

As I indicated, my presentation will focus on the future – a future where the ability to leverage information and information technologies will increasingly be a determining factor among those that succeed and those that are swept into the dustbin of history. We as a community need to do our part to help ensure that NATO is able to fully realize the promise of technology by providing answers to a wide range of questions regarding investment strategies and system design tradeoffs. SAS-002 has developed an excellent Code of Best Practice (COBP) for C2 Analysis that has provided us with a solid analytical framework and useful advice as well as a firm foundation to build upon.

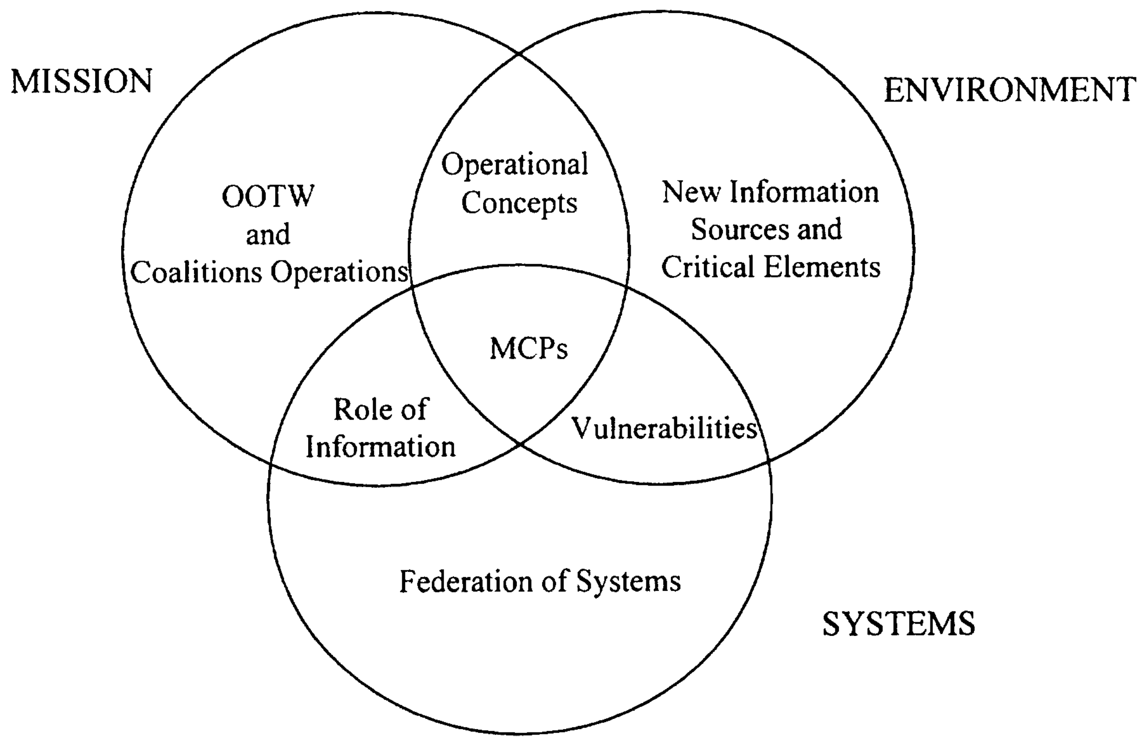
Today I would like to review with you the changes that have taken place in three key areas: the missions NATO is being called upon to undertake, the global information environment, and the nature of emerging systems. These changes have created a new set of challenges that need to be addressed by the C2 analytical community. I will share with you my candidates for the ones that require our immediate attention. My presentation concludes with a status report on SAS-E05, an exploratory team charged with charting the way ahead for C2 analysis.

BACKGROUND: A CHANGING WORLD

The end of the Cold War and the explosion in information technologies have combined to make life exciting. Figure 1: A Changing World, depicts three dimensions of change that affect our approach to analyzing C2 and its contributions to mission effectiveness and some of their impacts.

Figure 1

A Changing World



New Demands on Analytical Community

NATO is seeing an evolution of its traditional mission space as we are being called upon to undertake a variety of operations other than war (OOTW), including peace operations and humanitarian relief. NATO, soon to include new Member States, will need to continue to work with its Partners and an increasing number of non-member nations and variety of organizations (other international organizations, non-governmental organizations and sub-national population groups) in undertaking these challenging missions where tactical decisions often have strategic implications. In addition, there are heightened concerns over the threats from weapons of mass destruction and information operations. The explosion of information technologies and industries have changed the information landscape. The variety of information sources has increased dramatically and with it the kinds of information that were normally only available to a super power are

now available to almost everyone in real time. The nature of our systems is also changing. We are increasingly dependent on commercial off the shelf technologies (COTS) and commercial services.

These changes have resulted in the increasing importance of information. And as our dependency for information and connectivity grows, our control over our infostructure diminishes and our vulnerabilities increase. The changes in the nature of the missions we undertake and the information that is available demand new operational concepts. In fact, new mission capability packages (MCPs) are beginning to emerge with new command concepts, organizations, and doctrine to take advantage of the opportunities afforded by improved information and connectivity. All of these changes place new demands on our community.

C3I ANALYSIS CHALLENGES

On the top of my list of challenges is the development of new and improved measures. We need to develop measures that reflect mission accomplishment in OOTW. Clearly traditional measures of force effectiveness (e.g., loss exchange ratios, FEBA movement) are not applicable. With increased emphasis on coalition command and control and new approaches to command (e.g., self-synchronizing forces) we need appropriate measures. First, to see how well our systems and information support these new command structures and processes. Second, to see how the degree to which we execute these new command concepts relates to mission effectiveness – in a variety of missions. Information operations (IO) are not new but their potential potency and importance makes it important for us to understand how these effects interact with other effects on the battlefield. IO need to be characterized and related to their effects on adversary C2 as well as our own C2. As we become more and more dependent on systems of systems we need to be able to understand infostructure performance as opposed to the performance of a particular system. Obviously, we have plenty of work to do developing and testing new measures.

One of our old standbys methodologically is to simplify the problem at hand, either by concentrating on just a few key variables or by decomposition. Another approach has been to trust the increasing power of today's and tomorrow's computers to brute force, a solution with increasing numbers of variables. The increasing complexity of the problems we face will not always be responsive to these traditional approaches. We need better methods and tools to deal with increased complexity and similarly with non linearity.

The key to success will be our ability to co-evolve coherent information enabled MCPs. In order to do so we need models that can offer us the flexibility to change organization, command approaches and doctrine as well as systems performance characteristics. We also need models that adequately represent complex decision processes (e.g., distributed collaborative approaches) and the effects of IO. Many of our current tools are one sided in that the adversary is pretty much scripted. We need more truly n-sided models that

allow the players to react more realistically to changes in situations. In many cases, new tactics and capabilities will be explored. We need to allow for learning.

The final point I would like to make with regard to models is that all of us know that one model is rarely enough to provide all of the data one needs. Recent advances are making it possible to federate models so that situation and capabilities can be more accurately represented. We need to learn how to take advantage of federations of models and better understand their limitations.

Finally, validation, both to ensure the quality of analyses and to ensure credibility with decision makers, will become an even more important issue. Not only will the validity of the models and technical tools used be an issue, but also the validity of the concepts of operations, organizational assumptions, and capabilities assumed for future systems will be questioned. New tools and techniques for establishing credibility and testing validity will be needed. More "experiment like" approaches will be needed to ensure appropriate analyses and assumptions about soft factors (such as human decision making processes).

Clearly, I have put a full plate of C2 analysis challenges on the table. More, in fact, than we can focus on at one time.

SAS-E05

Because we do indeed face what could be characterized as a target rich environment, the NATO SAS Panel has formed SAS-E05, an exploratory team to make recommendations about the way ahead.

Work is now getting underway, with an orientation session for members of the Exploratory Team and some initial work on assignments and scheduling this week. Two meetings are expected, with a report to the SAS Panel due in November, 1999. Member nations are, of course, encouraged to join the effort and help define the way ahead.

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14. Abstract

The main objective for this Symposium was to exchange the latest research information in selected focus areas that must be addressed when conducting systematic and disciplined evaluation of C3I systems. A second objective was to provide an opportunity for NATO countries and PfP nations representatives to discuss examples of current best practices in C3I research, modeling, and analysis with recognized experts in the field.

The Symposium consisted of six sequential sessions and was based on the format used by the SAS-002 team to assemble its "*Code of Best Practice for the Assessment of Command and Control*" [RTO publication TR-9, AC/323(SAS)TP/4]. The opening session comprises a keynote address by French General Marescaux, an overview of the work of the SAS-002 team, and a presentation on significant aspects and contributions of the team's work. The other sessions are on Measures of Merit (Session 1), Modeling and Simulations (Session 2), Human Factors and Organizations (Session 3), Applications (Session 4), and Special Topics (Session 5).